Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

Vol. 12 SEPTEMBER, 1956 No. 9

SOMEBODY GOOFED!

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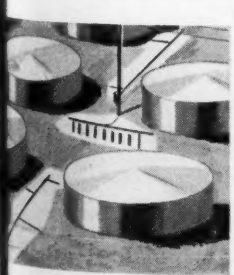
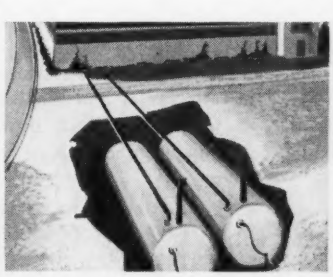
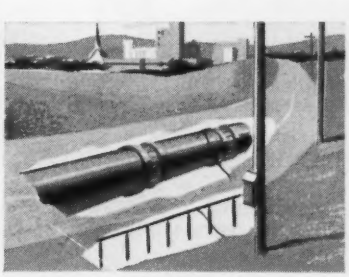


Tank farms



Underground storage tanks



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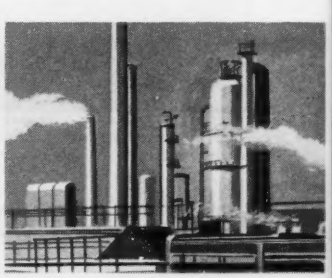

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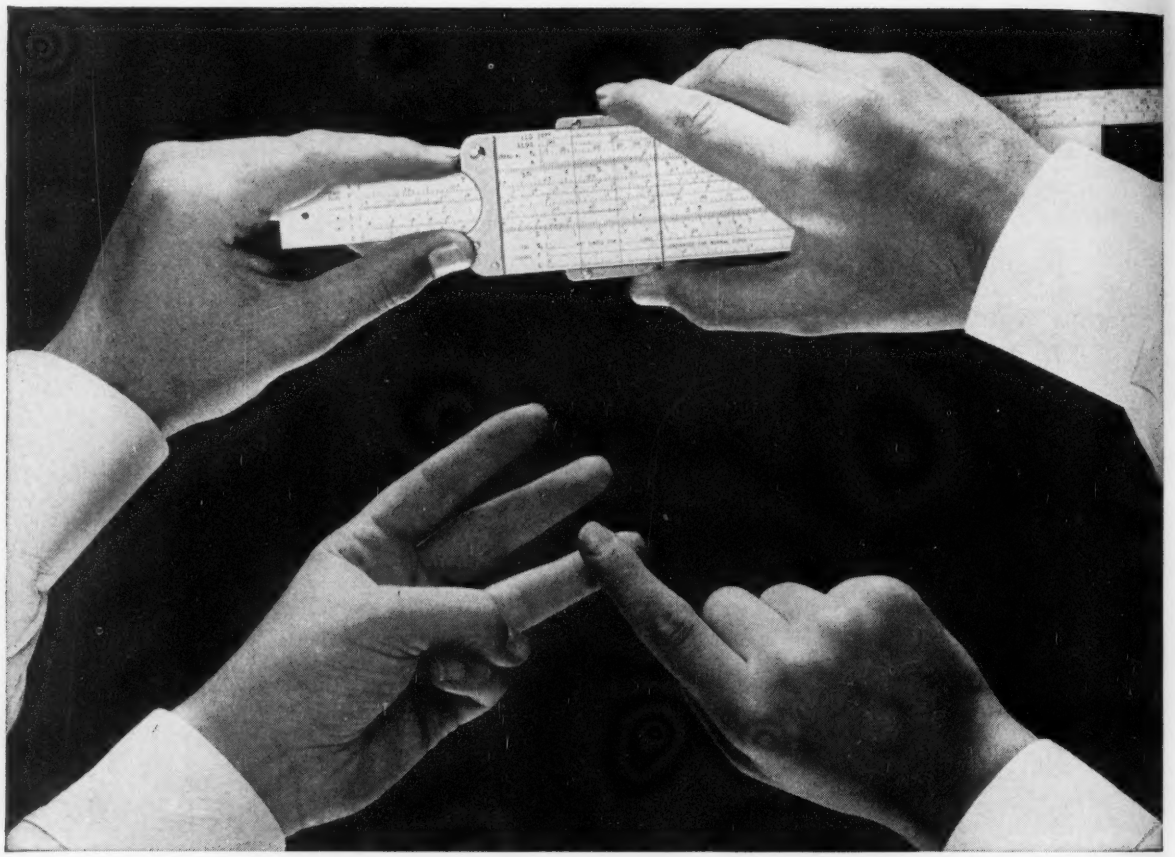

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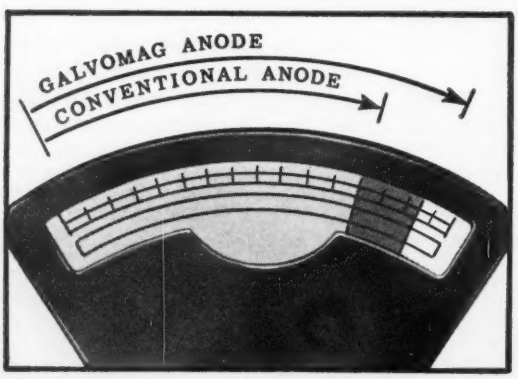

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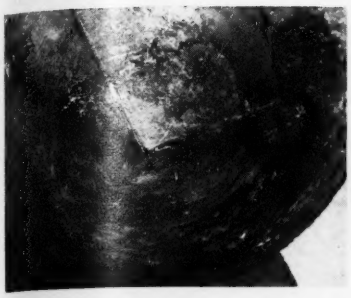

THIS MONTH'S COVER—Perforations in welded seams of this storage tank were attributed to galvanic corrosion between weld and basis metal by B. R. Guild, Carlsbad, N. Mex. Residual dry cleaning fluid in the conical end of the buried tank was the electrolyte. The ¼-inch thick steel was reduced by half near the welds. Tank was used between 1947 and 1950, then became an auxiliary to catch overflow of above-ground tanks.

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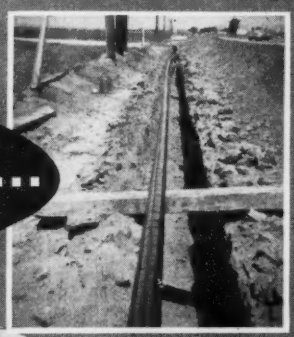

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- **T-5B-5 Corrosion by Molten Salts and Metals**

W. D. Manly, Chairman, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

T-5C Corrosion by Cooling Waters

- **T-5C-1 Corrosion by Cooling Waters (South Central Region)**

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M. Brooke, Vice-Chairman; Phillips Petroleum Co., Box 379, Old Ocean, Texas

W. W. Wheeler, Secretary; Rohm & Haas, Box 672, Pasadena, Texas

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R. E. Gackenbach, Vice-Chairman; American Cyanamid Co., Organic Chemical Div., Bound Brook, N. J.

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Wade Wolfe, Jr., Secretary, 73 Ermann Drive, Buffalo 17, New York.

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K. A. Phillips, Vice-Chairman, American Zinc, Lead & Smelting Co., P. O. Box 495, East St. Louis, Illinois.

W. B. Meyer, Secretary, St. Louis Metallizing Co., 625 South Sarah, St. Louis 10, Missouri.

- **T-5D-8 Methods and Criteria for Evaluating Plastics in Chemical Environment**

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R. Lembcke, Secretary, Cities Service Res. & Dev. Co., 920 East Third, Tulsa 3, Oklahoma.

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L. S. Van Delinder, Vice Chairman, Carbide & Carbon Chemicals Co., South Charleston, West Va.

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L. A. Ferris, Secretary, E. I. DuPont de Nemours & Co., Inc., Polychemicals Dept., Wilmington, Delaware.

- **T-6A-1 Heavy Linings**

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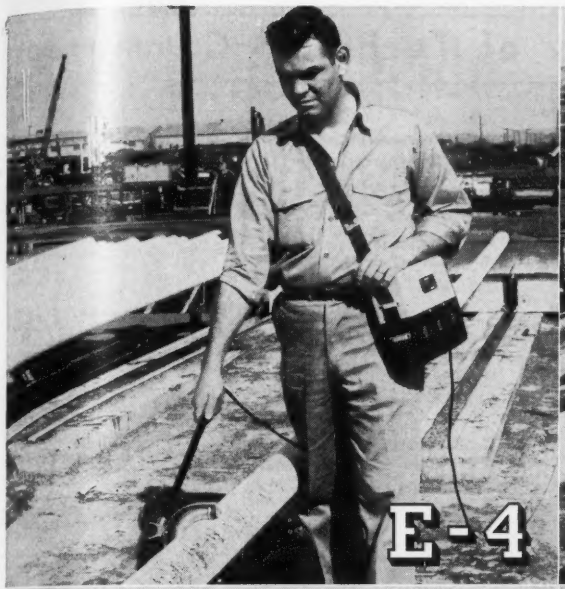
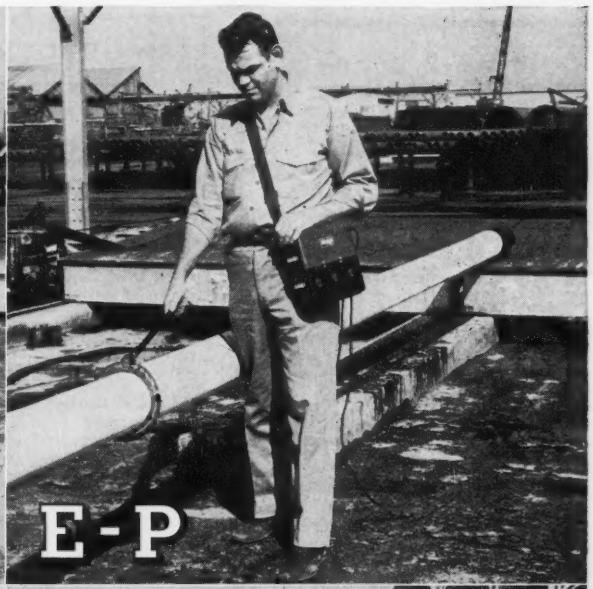
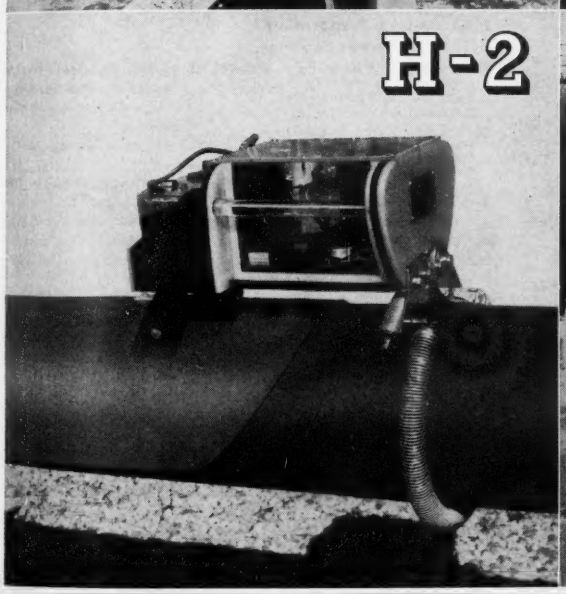
- **T-6-2 Vinyl Coatings**

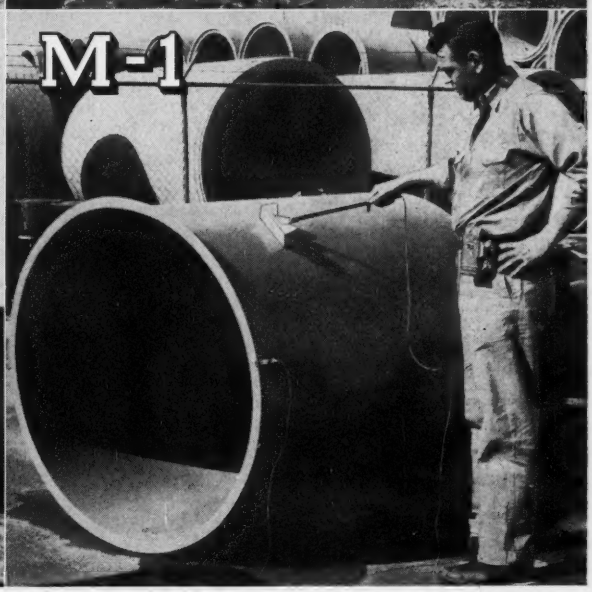
K. Tator, Chairman, 2020 Montour Street, Coraopolis, Pa.

(Continued on Page 8)









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J. H. Cogshall, Vice-Chairman, Pennsylvania Salt Mfg. Co., 3 Penn. Center Plaza, Philadelphia, Pa.

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C. A. Erickson, Jr., Vice Chairman, The Peoples Natural Gas Company, 140 Stanwix Street, Pittsburgh, Pa.

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L. Andrew Kellogg, Vice-Chairman; Niagara Mohawk Power Corp., 300 Erie Blvd., West Syracuse, N. Y.

T-7B North Central Region Underground Corrosion Coordinating Committee

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T-7C Southeast Region Underground Corrosion Coordinating Committee

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T-7D South Central Region Underground Corrosion Coordinating Committee

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T-7E Western Region Underground Corrosion Coordinating Committee

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J. S. Dorsey, Vice Chairman, Southern California Gas Co., 3249 Terminal Annex, Los Angeles, Calif.

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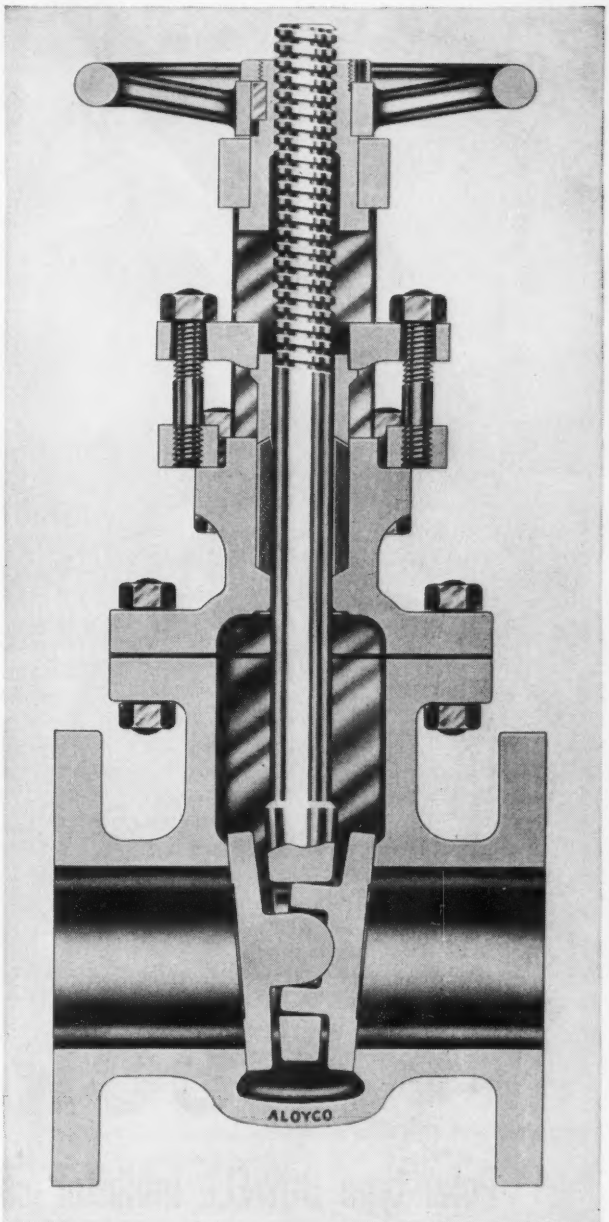

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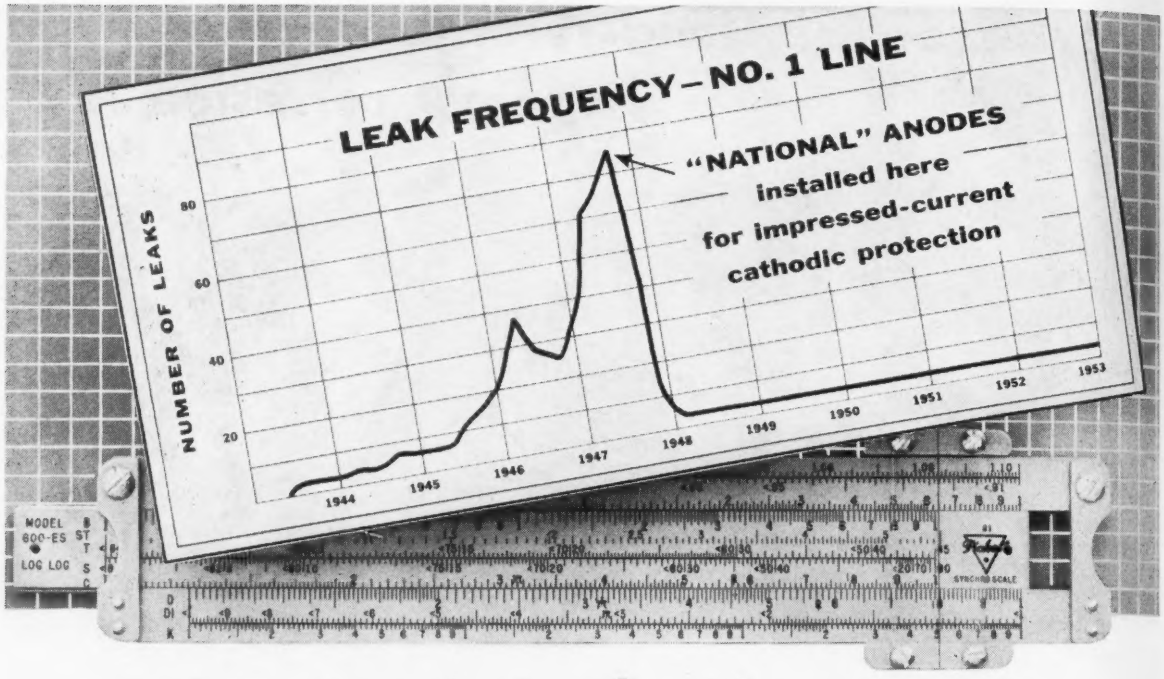

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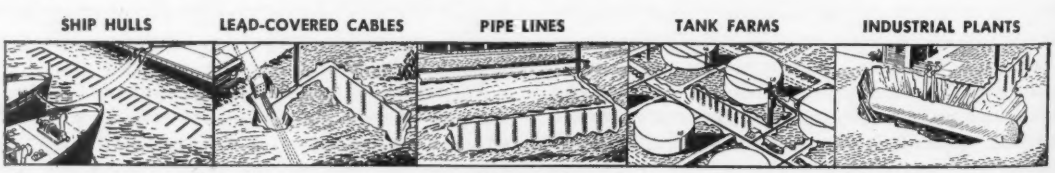

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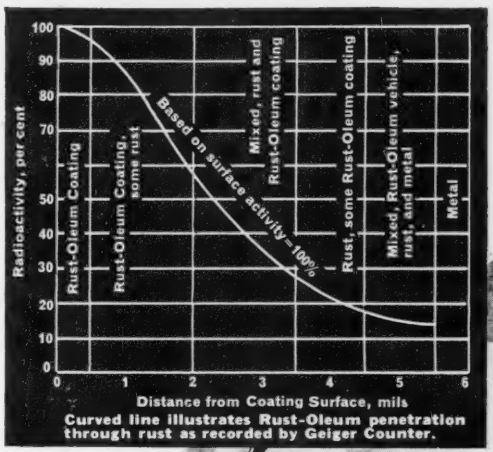

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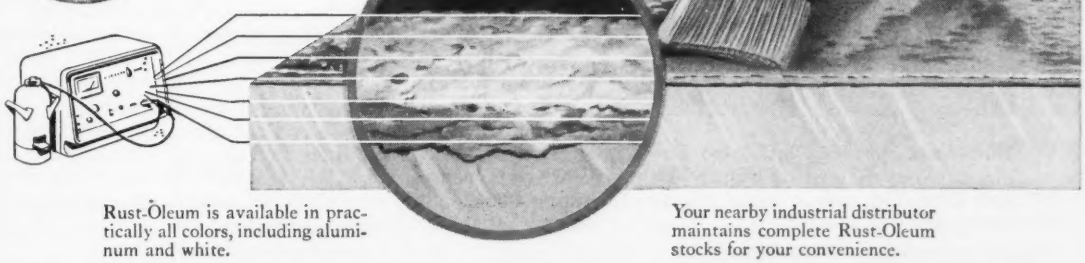

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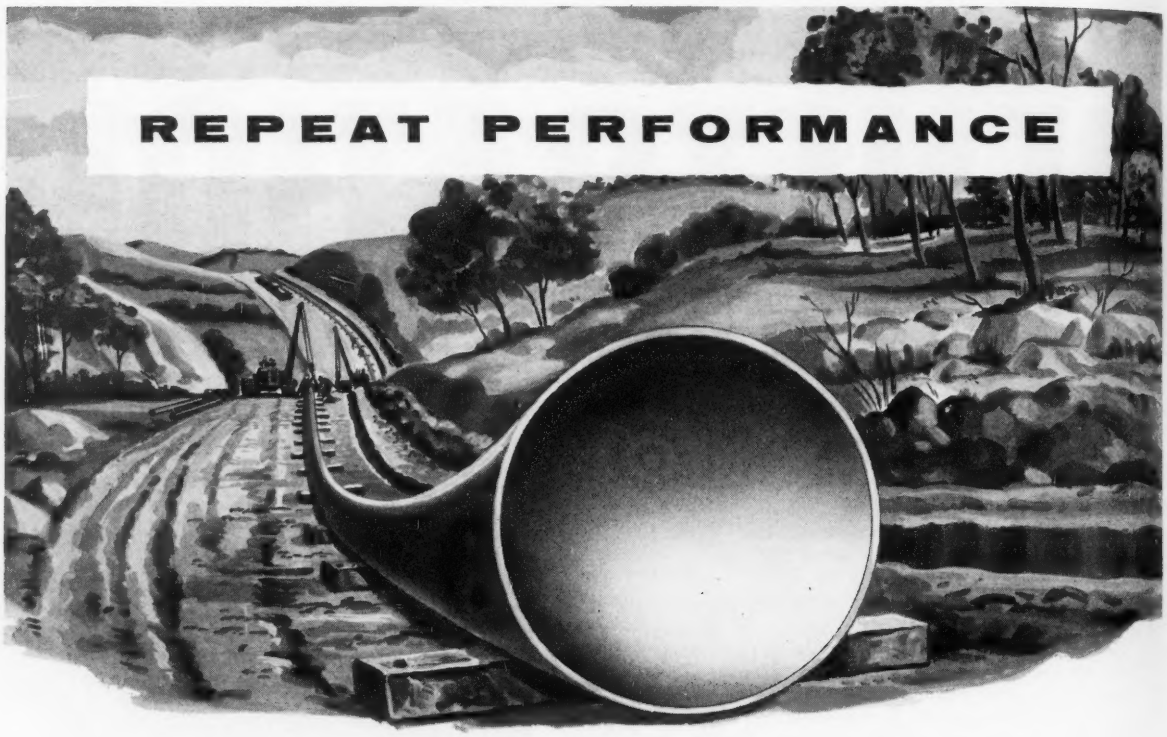
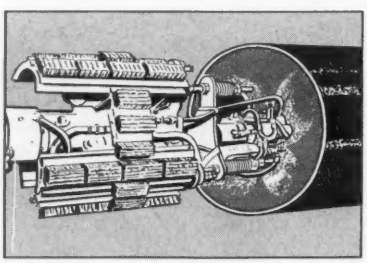


Copon internal pipe coating selected again by major gas transmission company



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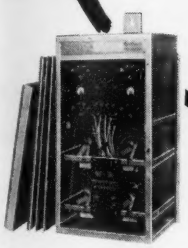

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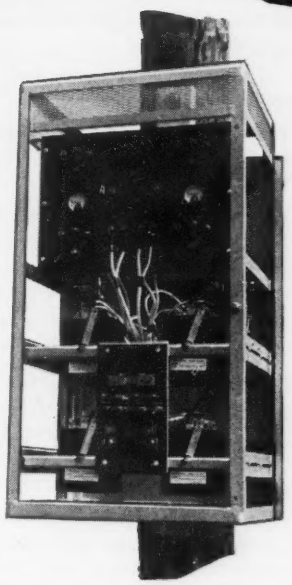

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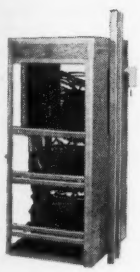

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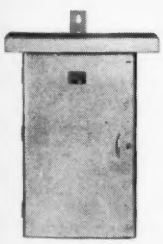

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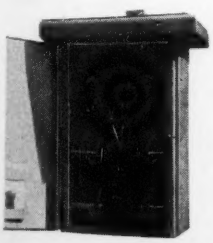

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(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

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Corrosion

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Two Cases of Corrosion in Suburban New York Disguised as Galvanic—Their Cause and Mitigation*

By W. SEARLE WOODWARD*

Abstract

Two cases are reported in which stray current potentials were mistaken for galvanic potentials from underground lead-sheathed telephone cables to ground. Lack of suitable meters prevented assessment of the true potentials of the cables which suffered severe corrosion damage.

Case 1 pertains to a relatively high stray current area adjacent to both the New York City subway system and the electrified New York Central Railroad. First tests showed steady positive potentials similar to those which might result from a galvanic source. When the fixed potential was blocked out by an opposite fixed potential, a marked fluctuation of potentials to earth was observed. Bonding reduced the cable-to-earth potential to a range of —0.1 to —0.4 volt.

Case 2 pertains to a section of cable where an average of 8.9 failures per 100 sheath miles per year occurred over an extended period of time. The damage began to occur shortly after discontinuance of a trolley system. A rectifier-powered cathodic protection system, installed in 1940, improved conditions on all but about 4,000 feet of the cable. Later, tests indicated alternating currents from the 11,000-volt, 25-cycle return of the New York, New Haven and Hartford main line were somehow related to direct currents on the sheaths; surges being correlated to railroad operation. The author postulates that the direct current may have been the result of the rectification of several AC potentials of different magnitudes over a large area. Corrections attempted by bonding a half-wave selenium rectifier to the adjacent railroad structure were successful, but a series of rectifier breakdowns, due to surges, was experienced. The use of a rectifier embodying a protective circuit, eliminated breakdowns, but additional testing and corrections are being made to bring the whole section to a potential which will reduce corrosion. 3.6.9

Introduction

IN NORTHERN New York City and the adjacent suburban area, the New York Telephone Company has experienced two cases of severe corrosion where cable-to-earth potentials and potentials to other structures were so constant that the corrosion was believed to be purely of a galvanic origin. This belief was held in spite of the fact that one case occurred in an area that had a large amount of stray current.

Until the acquisition in 1950 of more sensitive meters than those formerly used, it had been impossible, in many cases, to read sheath current with sufficient accuracy to determine pickup or loss of current within a single manhole section. For this reason, current loss measurements were not made in these cases until after 1950.

The meters presently in use in this area are of a duplex type with two identical movements in the same case. Each movement has a low scale of one millivolt for a full-scale reading. The two movements are a great asset in making measurements correlating shearth currents with cable to foreign structure potentials. The method used by the author in making such measurments is, in general, as follows:

> Assume a cable running through four consecutive manholes numbered for identification purposes one to four, as indicated on Figure 1. The area of suspected current loss lies between Manholes 2 and 3. A cable is selected that does not have branch cables in either Manhole 2 or 3. The cable is then inspected in Manholes 1 and 4 and bonded to all other cables in the manholes, if such bonding does not exist. This is required so that the subsequent readings will apply as nearly as possible to all cable in the conduit run.
>
> Millivolt drop readings are then made independently in Manholes 2 and 3. The arrangements of the leads is indicated in Figure 2. The two meter movements are read simultaneously at times of relatively high current. A group of five to ten readings are made and the arithmetical relationship between readings of each pair established. This gives the relationship between the current-caused millivolt drop across the two-foot piece of sheath and that across the whole manhole. If the relationship of one or two pairs of readings show a wide divergence from the

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* Engineer, New York Telephone Company, New York, N. Y.

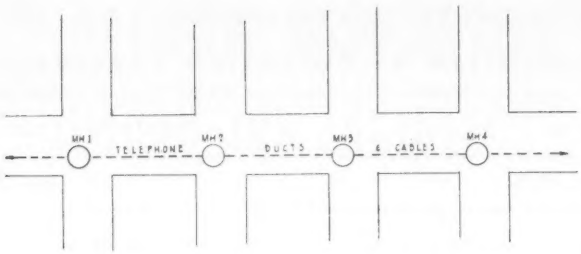


Figure 1—Arrangement of telephone ducts and cables.

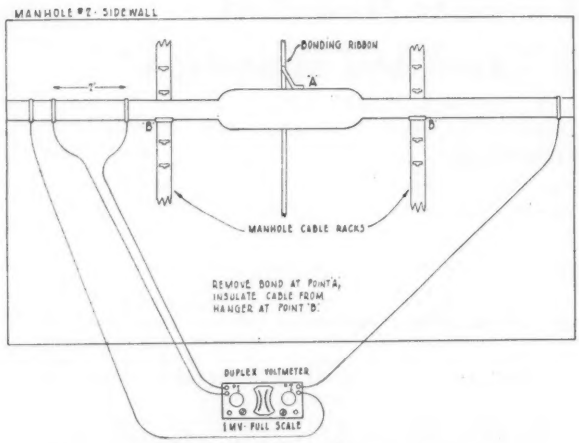


Figure 2—Arrangement of leads at Manhole 2.

others, these are discarded and the remainder averaged arithmetically.

Assume that the relationship established at Manhole 2 is 3.54 and at Manhole 3 is 4.2. Any reading made over the long drop at Manhole 2 is then comparable to a reading made over the long drop at Manhole 3, if divided by 3.54 over 4.2 or 0.84. The difference between the readings at either manhole gives a picture of whether current is being picked up or lost in the section concerned. Headings for a form for recording these readings are shown in Figure 3. When desired, the value in amperes can be found by referring back to the 2-foot drop at Manhole 3. This is seldom done, however, because the primary reason for the long drop or exaggerated scale is to show the pattern of the current loss, rather than its actual value. The loss pattern is required to determine a relationship between it and potentials to other structures, because, in many cases, the current loss is not completely related to the total sheath current.

The current is determined by making a fairly large group of readings over the large drop at each manhole. Simultaneously the cable to a foreign structure potential is taken at each manhole. Usually, the cable to foreign structure potential will be the same at either end of the section involved, so that only one potential reading is necessary. At the other meter location, the cable potential to a different structure is taken, so that from each group of four simultaneous readings, two different cable to structure potential are checked for a pattern that will correlate with the current loss. Figure 3 shows a typical current loss test with potentials to railroad tracks and a water main taken simultaneously.

Case 1[1]

Case 1 occurred within an area of relatively high stray current. Both the New York City subway system and the New York Central Railroad operated there with third rail at a nominal 650 volts. However, stray current was not suspected as a cause of the corrosion at this location because the cable to earth potential did not fluctuate over a 24-hour period as taken with smoked chart type of recording meters. The potential ranged from a constant positive 0.2 at the eastern edge of the corrosion area to a positive 0.7 in the center. The potential was measured to a lead chloride half cell in the manhole; the lack of fluctuation led to the assumption that the corrosion was entirely galvanic in origin. Thus, the problem became one of discovering what produced the galvanic potential.

A potentiometer and battery were used in further work in which the fixed potential was blocked out to a point where the voltmeter could be switched to the 50 millivolt scale (see circuit in Figure 4.) On the 50 millivolt scale a decided fluctuation of the earth potential was indicated. The actual reading in millivolts was meaningless, however, because of the bridging effect of the potentiometer. At this time, a current-loss test was made with a cable-to-rail potential at one manhole and the cable to earth fluctuation was indicated in divisions of scale reading at the other. This was the area indicated on Figure 3 with the cable-to-earth differential substituted for the cable-to-water potential.

Excellent correlation was obtained between the current loss, cable-to-earth differential and cable-to-rail potentials. This test established the fact that the freight yard was controlling the cable-to-earth potential fluctuation which in turn controlled the current loss from the telephone cables. The railroad representatives agreed to a drainage bond installation from the telephone cables to the freight-yard rail. This rail was in turn connected to the main-line rail through a reactance.

Immediately following the installation of the bond with an average drainage of 30 amperes and peaks of 85 amperes, the cable-to-earth fluctuation was found to be approximately 0.2 volt. This fluctuation only tended to reduce the positive potential without reversing it. About two months later, the cable-to-earth potential fluctuation was found to be —0.1 to —0.4 volt.

Case 2[2]

Over a period of 15 years, the Boston Post Road in Port Chester, N. Y., and Greenwich, Conn. has been an area particularly susceptible to corrosion. The importance of this section to the telephone company lies in the fact that it is part of the only direct underground route between New York, White Plains, and Boston.

The 15-year period referred to above began approximately six years after the discontinuance of the New Rochelle-Stamford trolleys and of the associated negative return drainage they had provided. This condition has resulted in nearly 100 sheath failures, requiring section replacements at an average cost of more than $1,000 per section. This gives an average of 8.9 failures per 100-sheath miles per year. Figure 5 indicates the 6-year time lag and also the wide variation in the subsequent failure rate.

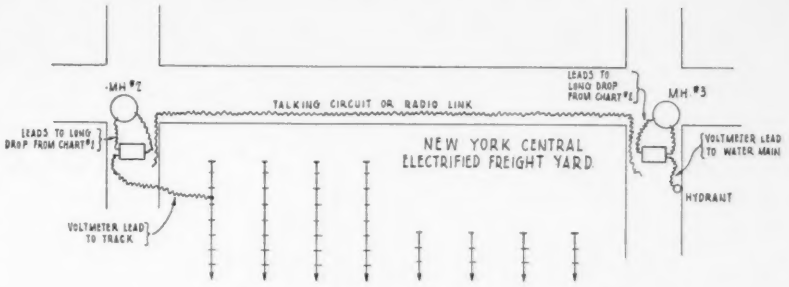
Tests made before 1950 disclosed what was believed to be a galvanic condition. The test results indicated a very small direct current in the sheath. The magnitude of this current was too small to permit quantitative measurement or any attempt to establish a current pattern with the use of recording meters. The earth potential varied at different locations from 0.5 to 0.75 volt with the sheath positive to earth measured to a lead chloride half cell. However, at any given location, the potential did not vary appreciably over a 24-hour period as indicated by charts made with a recording meter. Figure 6 is a schematic diagram of this area. The dashed line indicates the sections in which failures occurred. The numerator of the associated fraction is the number of manhole sections involved and the denominator the number of cable replacements in the section indicated.

The first large scale mitigation attempted in this area was the installation of two point anodes in 1940. One of these anodes was installed in the Byram River in Port Chester. It consisted of a network of steel I-beams. The other anode was attached to an abandoned mill wheel in the Mianus River. The power to each of these anodes was supplied by a 12-ampere, 75-volt Tungar rectifier with the negative side connected to the cable sheath at various points along the route, the drainage at each point being controlled by the resistance of the conductors to that point. The possible total of 24 amperes drainage was in excess of any measurable DC current flowing on the sheaths.

Lead Duct Anodes

This system generally resulted in an improvement in cable-to-earth potentials with the exception of two sections each approximately 2,000 feet long. To provide mitigation for these sections, lead duct anodes were installed. Each anode was energized by its own rectifier of 12-ampere capacity. Duct slug tests made following these installations showed a decided improvement in cable-to-earth potentials over the original conditions, but were still far from satisfactory even with all rectifiers working at capacity.

The next attempt was the installation of a distributed anode system over a length of approximately one-half mile. This was powered by a 12-ampere rectifier and the current to each anode was controlled by resistances.


MH #2
TALKING CIRCUIT OR RADIO LINK
LEADS TO LONG DROP FROM CHART #2
MH #3
LEADS TO LONG DROP FROM CHART #1
NEW YORK CENTRAL ELECTRIFIED FREIGHT YARD
VOLTMETER LEAD TO WATER MAIN
HYDRANT
VOLTMETER LEAD TO TRACK

M.H. 2			M.H. 3				
POT. TO RAIL	CURRENT (IN DIV.)	CORRECTED CURRENT	EARTH POTENTIAL	CURRENT (IN DIV.)	CORRECTED CURRENT	CURRENT LOSS	CURRENT PICKUP

Figure 3—A typical current loss test. Potentials to railroad tracks and a water main are taken simultaneously.

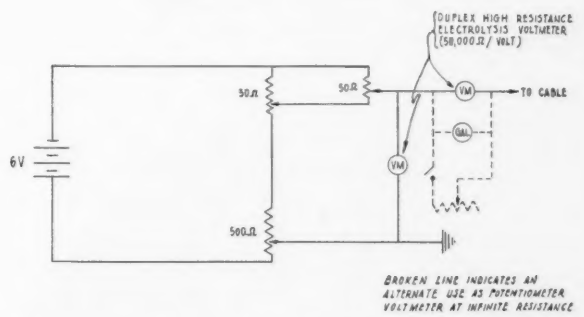


Figure 4—Circuit for measuring small variations in earth potential in presence of relative high galvanic potentials.

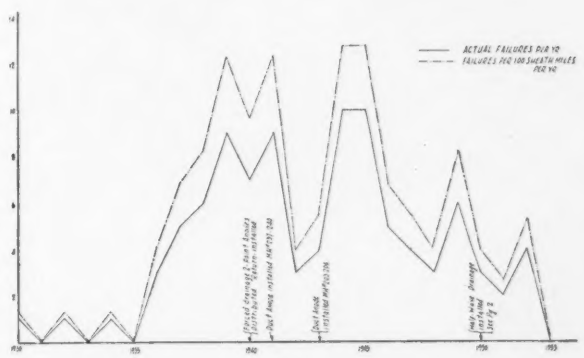


Figure 5—Telephone sheath failures from electrolysis on the Boston Post Road between Manhole 154 (Rye) and Manhole 245 (Mianus River). Data were collected following abandonment in 1929 of New Rochelle-Stamford Trolley. Length measured was 72.2 sheath miles (6.67 route miles).

Duct slug tests were made before and after the installation of this system. The tests indicated an improvement in some sections, but for some reason not apparent, the positive potentials were increased in other sections. This system was subsequently abandoned as not justified.

Following the development of the improved instrument previously mentioned, further testing was done in this area. With the aid of these meters, it was

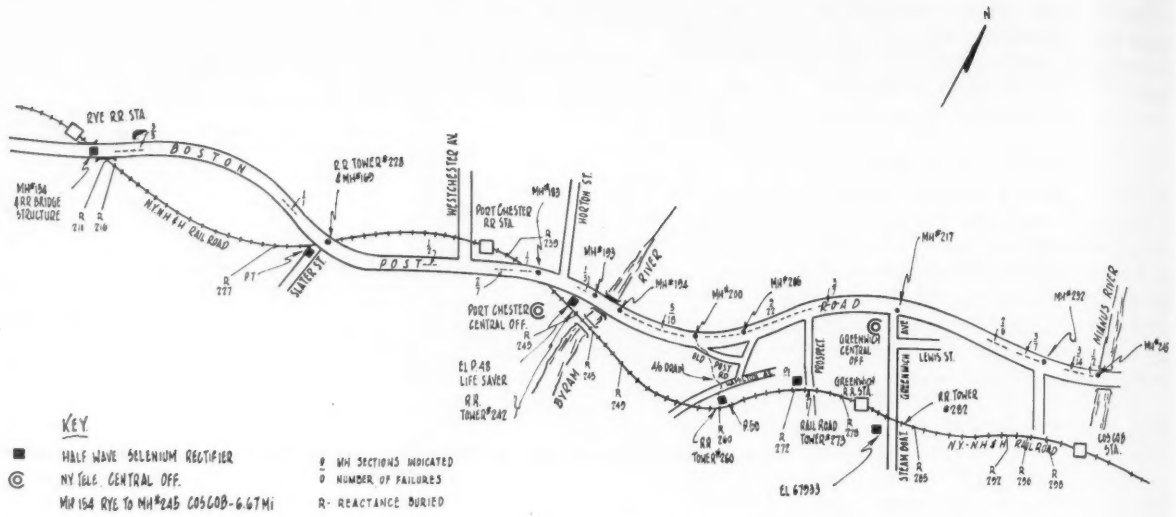


Figure 6—Sketch indicating half wave drainage locations to New York, New Haven and Hartford Railroad.

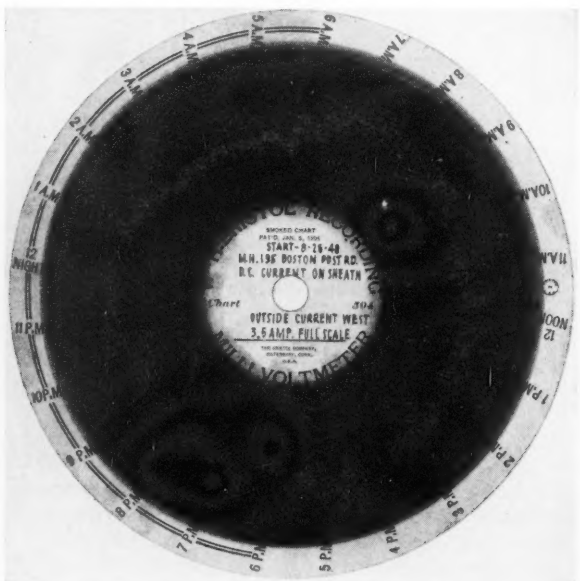


Figure 7—DC current on telephone cable sheaths (Manhole 195, Boston Post Road, East Port Chester, Conn.) A series of cable failures occurred in Con Edison's Waterside Station on August 26, 1948, beginning at 8:17 p.m. This system provides part of the power for the New Haven Railroad.

found that the sheath current had a definite traction pattern. The New York, New Haven and Hartford Railroad's main line parallels this subway but was not considered as a factor as it operated from an 11,000-volt, 25-cycle, single-phase line. However, by chance, a recording of sheath direct-current was being made at the time of a power failure on the New Haven, west of the point of test. It was noted that the sheath current indicated a relationship to the New Haven operation by reversing its direction and increasing its magnitude at the exact moment of failure. This was recorded as is indicated on Figure 7.

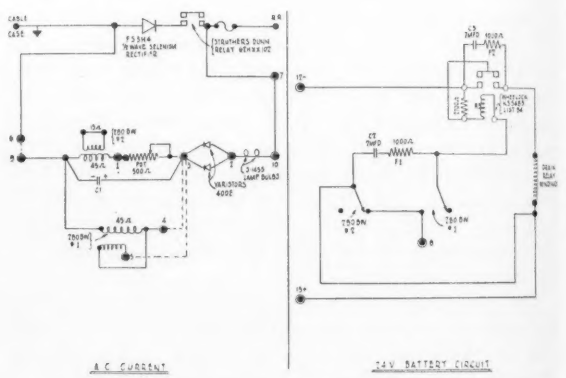


Figure 8—Schematic for half wave drainage circuit.

Correlation of Sheath Current and Sheath Potential

A further indication of relationship is indicated by surges in sheath current and earth potential which could be correlated to trains under load reaching the break in New Haven overhead at the Cos Cob bridge. There was also a good correlation between sheath current, earth potential and inverted DC potential to the New Haven structure at a remote location (see Figure 6.) That is, the sheath current at Manhole 195 east of the Byram River correlated with the sheath potential of the cable at Manhole 195 to the railroad structure at Tower No. 282, Greenwich Avenue, a distance of approximately two miles.

The inversion is indicated by the fact that the higher the east current, the more negative the cable became to the structure. Conversely, when the current reversed and flowed west, the cable became positive to the structure to the east, the potential increasing with the current. The only condition known to the writer which will produce this inversion is the assumption that the potential is measured across a half-wave rectifier. Unfortunately, very little success was experienced in attempting to correlate sheath current or earth potentials with an AC potential to

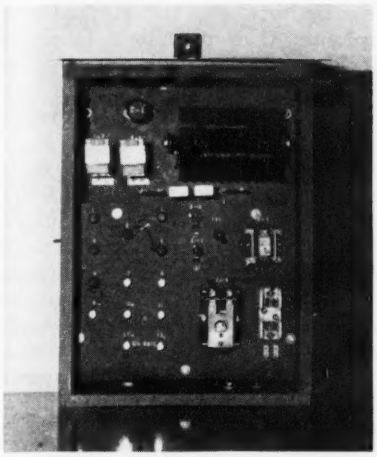


Figure 9—Half wave protected rectifier.

the New Haven. It may be that the AC potentials observed have been local in character, whereas the DC potential may be the resultant of several AC potentials of different magnitude over a somewhat larger area.

Other tests made seemed to indicate also that the corrosive current was of alternating current origin. These tests were made at Manhole 213 and 213½ in Greenwich. Simultaneous potential measurements made between three half-cells, one over the cable run, measured to a half cell to the north, and one to the south of the cable run, indicated a direct current of varying quantity leaving the cable run at the same time sheath current measurements were made at both manholes. These readings indicated a pickup of current in this section of cable. Also, simultaneous readings were made of the variation in cable-to-earth potential, using the potentiometer described in Case 1 to offset the fixed cable-to-earth potential existing in these manholes. Correlation between all five sets of readings was good.

A possible hypothesis explaining the readings was that there was a transfer of alternating current between the cable and earth at this point which was partially rectified. The half wave leaving the cable resulted in the earth current potentials noted with the half cells.

Another group of tests which added to the evidence was made with the cooperation of the New Haven Railroad. In this group, almost perfect correlation was established between the direct current on the telephone sheaths with the direct current on the New Haven running rails. At this time, it was possible to see a relationship between the direct current and train movement.

Drainage Connections

Six locations were selected for drainage connections where existing telephone cables were adjacent to the railroad structure. The connections were made through a 20-ampere fuse and a half-wave selenium rectifier consisting of ten 5-inch plates in parallel. No immediate change in cable-to-earth potentials resulted, although current recordings indicated a drainage of 12-15 amperes at peak loads. However, after approximately six weeks, a decided pattern in the cable-to-earth potential became evident and after three months, approximately one and a half miles of subway, which previously had been continuously positive to earth by .15 volt, was negative and fluctuating between —.05 and —.2 volt.

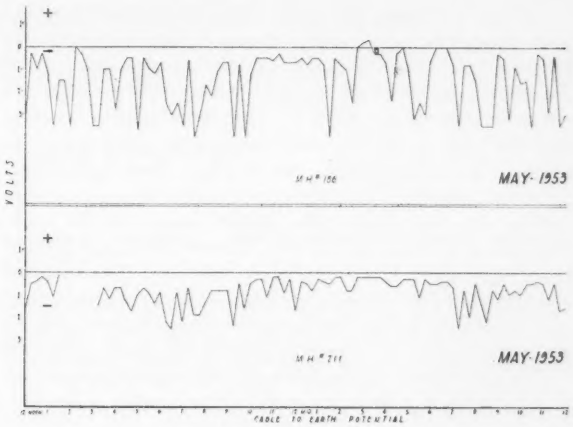


Figure 10—Cable to earth potential for Manholes 186 and 211 in May, 1953. Vertical ordinate is in tenths of a volt.

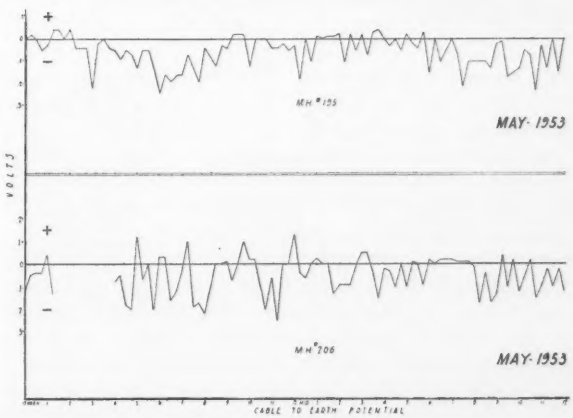


Figure 11—Cable to earth potential for Manholes 195 and 206 in May, 1953. Vertical ordinate is in tenths of a volt.

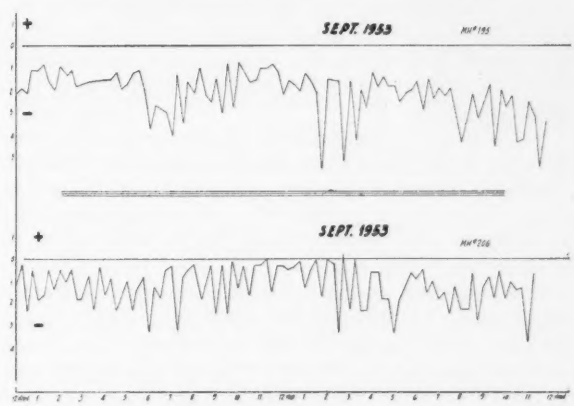


Figure 12—Cable to earth potential for Manholes 195 and 206 in September, 1953. Vertical ordinate is in tenths of a volt.

About this time a series of rectifier breakdowns was experienced, caused apparently by an excessive inverse potential. In many of these breakdowns, the 20-ampere fuse did not operate, which indicated a surge of short duration. Also, it was impossible to correlate the time of failure with any known railroad operation. At other times, there were fuse operations without rectifier damage and without a traceable cause. At this stage, the maintenance of the half-wave drainage was clearly impossible from a cost point of view. Even if there had been no rectifier breakdowns, the fuse operation was so frequent that the drainage connections were in operation only a small portion of the time. Several types of resetting breakers were tried and discarded for one reason or another.

Protective Circuit

It became apparent that the requirement was for a breaker that would open under an excessive potential and remain open for the duration of the excess and then reclose. To meet this requirement a protective circuit was designed. The final arrangement of this is shown on Figure 8. The inverse potential across the main drainage rectifier is utilized for the control circuit. A varistor mounted in the reverse direction to the main rectifier provides a direct current which is a function of the drainage current. This current is utilized to energize two polar relays. The first relay controls the breaker under overload and the second relay is required to provide for the opening of the breaker under the zero current condition in the control circuit, which would occur with the failure of any one of the components of that circuit.

The ballast lamps designated were used because of their low cold resistance. The use of three lamps in series limits the reverse current to approximately 300 milliamperes and retains control circuit operation with potentials up to approximately 90 volts. Figure 9 shows the drain rectifier together with its associated control circuit arranged for pole mounting. The case is 22 inches high, 18 inches wide and 9 inches deep.

Following the installation of the protected rectifiers early this year, there has been a gradual shift in the cable potential-to-earth with the cables becoming more and more negative. A series of smoked chart recordings were made. These charts were made at each location where a subsidiary cable terminated on a pole adjacent to the subway. The potentials were then measured between the subsidiary sheath and a ground rod driven at the base of the pole. The actual reading was then corrected by the measured galvanic potential between the ground rod and a piece of lead sheath. It is believed that this method gives a more accurate picture than potentials taken within the manhole, where in most of this area, some or all of the cables are under water. Copies of two of these which were considered satisfactory, reproduced in straight line form, are shown in Figure 10.

Figure 11 indicates a still partially positive area at Manholes 195 and 206. Tests showed that the worst of this area centered near Manhole 200. An inspection of the cables at this location made possible by a subway reinforcement showed the sheaths to be badly corroded (see Figure 6.) The nearest half-wave rectifier was at P.50 Hamilton Avenue and its initial connection with the Post Road consisted of more than a mile of small aerial cable. The result was that drainage at this location averaged only approximately one fourth of that at the other rectifier locations. To take advantage of the unused capacity of the rectifier and in the hope it would arrest the corrosion near Manhole 200, it was decided to place a 4/0 wire in the shortest route practicable between Manhole 200, Boston Post Road and P.50 Hamilton Avenue in advance of general acceptance of the system. A comparison of Figures 11 and 12 indicates the result of this reinforcement. It is believed that the installation of an additional rectifier near the Cos Cob railroad station and a 4/0 wire connection to the Post Road will render this area safe from corrosion.

Tests were made of the potential to earth of other structures where practicable (i.e., hydrants to adjacent catch basins or metallic street lighting poles to catch basins.) In most of the cases tested, no effect of the telephone drainage could be seen. In a few instances, the peaks of the telephone drainage could be seen but in no case was the change more than 30 millivolts.

The testing described under Case 2 is being continued with the cooperation of the New Haven Railroad.

Note: The additional rectifier near the Cos Cob railroad station previously referred to was not installed until February, 1956. With the exception of the section drained by this rectifier there have been no cable replacements required by corrosion in the area described since 1953 (Figure 5.)

References

1. C. E. Kreutzberg. Unusual Masking Effects of Galvanic Potentials on Lead Sheathed Cable. (A paper presented before the Greater New York Committee on Electrolysis, April 29, 1953.)
2. W. Searle Woodward. An Experiment in Half-Wave Drainage as a Means of Electrolysis Mitigation. (A paper presented before the Greater New York Committee on Electrolysis, December 3, 1953.)

Any discussions of this article not published above will appear in the December, 1956 issue.

Steel Surface Properties Affect Internal Corrosion Performance of Tin Plate Containers*

By A. R. WILLEY, J. L. KRICKL and R. R. HARTWELL

LAST YEAR, 39 billion metal cans were manufactured in the United States. To do this job, the container industry used a variety of tin mill products, which comprise roughly 8 percent of all finished steel production and which include black plate, chemically treated steel, hot dipped and electrolytic tin plate and short ternes. Of these, tin plate by far outweighs the others, 4.8 million net tons being made in 1954.

Tin plate is thin (0.01-inch) low carbon steel covered on each side by a much thinner (0.000015 to 0.00009-inch) layer of pure tin with strata of tin-iron alloy between. For many years, all tin plate was made by the hot dip process in which pickled steel sheets are fluxed and passed through a bath of molten tin. In 1937, however, following the development of the tandem cold reduction mill, tin plate made by the continuous electrotinning method first assumed commercial significance, and the economies associated with this process have resulted in its gradually replacing tin plate made by the older method. Hot dipped plate currently accounts for only slightly more than one-fourth of total production, but the disproportionately greater quantity of tin which it requires provides a constant stimulus to find still further applications for electrolytic tin plate. A natural consequence of the increased use of the latter has been the conservation of a strategic metal, the average weight of tin coating for all products now being less than half of what it was 15 years ago.

One of the more important properties of tin plate containers is their internal corrosion resistance. This property, usually referred to as the "corrosion shelf life" or "service life," may be defined here as the length of time required for internal corrosion to 1) liberate sufficient hydrogen to cause distention of the can ends or, 2) perforate the container. As the tendency for reaction between containers and contents is present in all moist food products the one major concern is that the service life of the container be longer than the time required for distribution and consumption.

In the mildly acidic, oxygen-free environment generally present in most canned foods, tin is anodic to iron and normally provides electrochemical protection to the small exposed areas of steel.[1,2,3] In plain (unenameled[(1)]) cans the difference between good and poor corrosion resistance is fundamentally the difference in the steel's ability to receive galvanic protection by tin. Many tin plate properties influence corrosion resistance, and the effects of such things as tin coating weight,[4,5] porosity,[4,5] steel composi-

A. R. WILLEY—Senior research chemist at American Can Company's Research Center at Barrington, Ill., he has done extensive experimental work on development of special methods to evaluate tin plate performance, especially its corrosion resistance. His recent work includes a study on the corrosivity of foods. He has published a paper on an electrolytic method for determining tin coating weights. A member of ACS, he received a PhD in chemistry from the University of Wisconsin and has been with Canco since 1937.

J. L. KRICKL—For the past seven years he has worked chiefly on problems of evaluating corrosion resistance of tinplate and of translating improvements in plate quality into practical measures of tin conservation with the Metallurgy Group of American Can Company's Technical Service Division. He joined the company after receiving a BS from St. Mary's College and an MS in chemistry from University of Illinois.

R. R. HARTWELL—Assistant to Manager of American Can Company's Technical Service Division, has had a particular interest in the corrosion performance of tin plate for a number of years. He is currently responsible for the coordination and establishment of all container material specifications. Since joining the company in 1935, he has written five papers concerning the use of tin plate. He received his technical training at the Massachusetts Institute of Technology, where he graduated with an SM in 1931.

Abstract

Two easily-performed laboratory tests have been developed which give results correlating with internal corrosion performance of plain electrolytic tin plate containers. One, the "rate of pickling" test, measures a permanent surface property of the steel arising in the annealing operation. The other, the "iron solution" test, measures the effect of certain factors governing the nature of the steel surface prior to electrotinning and to some extent the effect of the plating operation itself.

Tin plate manufacturers have used these tests as guides in improving the corrosion resistance of their product. The described tests, however, are not entirely adequate to account for all of the existing variations in corrosion performance believed to be related to steel surface characteristics. Additional work is required. 7.5.2

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(1) The term "enamel" is used in the container industry to denote a large variety of organic coatings which are applied to tin plate to prevent discoloration of some products, provide color retention for others and in certain instances control corrosion.

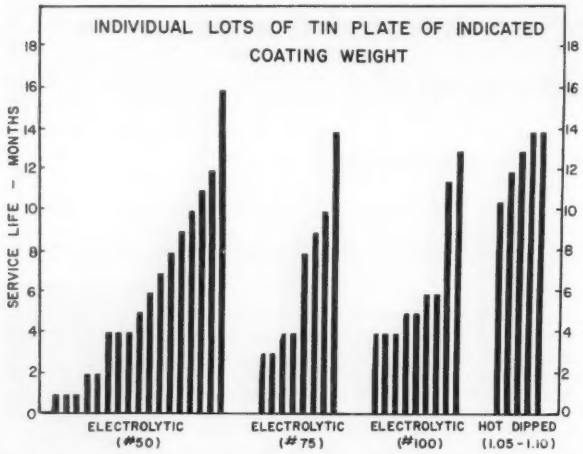

Figure 1—Variations in service life of plain electrolytic and hot dipped tin plate containers in 1943. Test pack medium: Grapefruit Juice at 100 F storage.

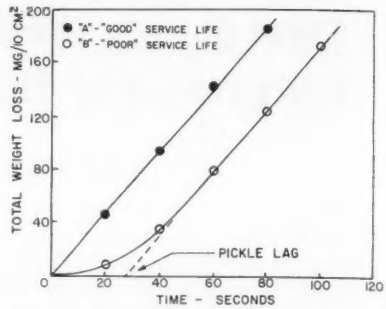

Figure 2—Rate of pickling tests in 6 N HCl at 90 C on base steels from tin plate with good corrosion resistance, "A", and poor corrosion resistance, "B". Both lots made from same heat of steel.

tion[5,6,7] and structure[5] have been investigated and reported. All other things being equal, increased tin coating weights prolong shelf life, but porosity is not considered an important factor. Because only high grade tin is employed for tin plate, there cannot be much variation in its content of foreign substances and there is no indication that the amount which does occur affects shelf life. Steel composition and structure have been considered most important to corrosion resistance and for practical purposes it may be said that where plate is the direct cause of unusually early corrosion losses, experience has shown that the nature of the steel has been the principal factor.

There is no single test which fully predicts the corrosion performance of tin plate for all of its uses. Consequently, it is customary to study this subject by making containers from tin plate, packing with appropriate foods and measuring the time required to produce container failure. The particular food product chosen naturally depends on the objectives, but for such work as reported here, dried prunes often are used on the basis of their year around availability and the speed with which they give results.

The practical aspects of the many years' work can makers and steel producers have devoted to tin plate reached their culmination early in World War II when, to conserve tin, electrolytic plate was widely tested for products previously packed only in hot dipped plate. Lightly coated (No. 25 and No. 50)[(2)] electrolytic plate, when enameled, proved entirely satisfactory for many of the mildly corrosive products. These early successes are reflected in the fact that today a number of large volume items are packaged in this style of container.

Disappointing, however, were the trials with the heavier electrolytic coatings (No. 75 and No. 100) which were primarily intended for plain cans for products where enameled containers are not considered suitable. The nature of the problem is depicted in Figure 1 and is in contrast to the consistently satisfactory corrosion performance of the enameled plate referred to above. While some electrolytic plate in each coating weight was equivalent or superior to hot dipped plate, the obviously erratic behavior of the former made its commercial application unattractive. None of the factors then known to affect corrosion resistance nor any then existing test for tin plate quality could explain the observed variations in performance.

Since 1942, a considerable amount of effort has gone into determining the causes for the behavior typified by Figure 1 and two new factors which are associated with the steel surface have been shown to influence corrosion shelf life. Control of these factors has made heavily coated electrolytic plate a useful can making material and tests have been developed to measure the intensity of each. The first factor is demonstrated by the "rate of pickling test" which is performed on the base steel. The second factor is measured by the "iron solution test" which is applied to the finished tin plate. It is the purpose of this paper to discuss these tests, the phenomena associated with them and their correlation with tin plate performance.

The Rate of Pickling Test

Investigation in 1945 of the behavior of two related lots of electrolytic tin plate led to the recognition of a steel surface condition which has been called the "pickle lag" phenomenon. The two lots of plate were of special interest because they had their origin in the same heat of steel, possessed identical tin coating weights and yet exhibited a threefold difference in service life pack performance, thus making it apparent that the steel was much more efficiently protected in one than in the other.

Because the protective effect of the tin on the steel base plays such a large role in determining shelf life, one of the customary ways to study container corrosion in the laboratory is by means of galvanic couples of tin and the steel bases of various tin plates. For such work, weak (approximately 0.2 M) solu-

(2) In the tin plate industry the unit of measure is the base box (112 sheets 14 x 20 inches each or 31,360 square inches). Tin coating weights are measured in pounds per base box (lb./BB). Hot dipped coatings are known as "Common cokes" and "Standard cokes" and require 1.25 and 1.50 lb/BB respectively for their manufacture. To distinguish them from the hot dipped coatings, electrolytic coatings are designated No. 100, No. 75, No. 50 and No. 25, and carry 1.00, 0.75, 0.50 and 0.25 lb/BB respectively.

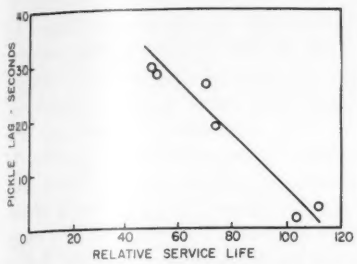

Figure 3—Relationship between pickle lag and service life on six lots of tin plate from same heat of steel. Test pack medium: Prunes at 100 F storage.

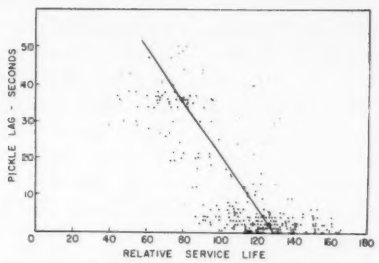

Figure 4—Relationship between pickle lag and service life of tin plate of varied origins. Test pack medium: Prunes at 100 F storage.

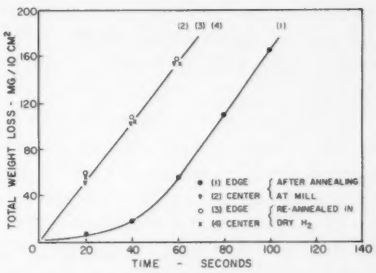

Figure 5—Rate of pickling tests on steel panels before and after laboratory re-annealing in dry hydrogen for one hour at 1250 F. Samples taken from center and edge of same sheets of tin plate where latter refers to region next to edge of coil as box annealed.

tions of citric acid or citrate buffers are frequently used and it is conventional to use standardized polishing techniques for preparation of the surfaces. Using these procedures, it was not possible to demonstrate any significant difference between the steel bases. Similar tests, made on unpolished specimens, however, gave the results in Table 1 which indicate that although the steels are of the same composition, they have different corrosion properties in that one is much more difficult to protect than the other. It is further indicated that the difference lies in the surface layers and removal of a sufficient quantity from the "poor" steel makes it behave substantially the same as the "good".

While the data in Table 1 showed tin-iron couple tests could detect differences in base steels, it was considered impractical to make a large number of them. It was also thought a direct measure of the responsible factor would be more desirable than one of its net effect and both of these aspects provided considerable incentive for the development of a quick laboratory test. This was finally found with the observation that detinned unpolished specimens of "A" and "B" (Table 1) reacted differently when immersed in hydrochloric acid. Successive weight loss measurements on the two steels in 6 N hydrochloric acid at 194 F (90 C) produced the results shown in Figure 2 from which it is evident that sample "A" pickles at a constant rate while sample "B" attains the same rate only after an initial period of inhibition. Extrapolation of the linear portion of the curves to the horizontal axis furnishes a convenient method for defining this behavior and the distance, measured in seconds, between this intercept and the origin of the curve is termed the "pickle lag". Thus, samples "A" and "B" have pickle lag values of 0 and 27 seconds, respectively. (Further details on the operation of this test appear in Appendix A.)

TABLE 1

Galvanic protection afforded by tin to base steels. Effect of steel surface removal by HCl. Test medium—air free citrate pH 4.0—24 hours at 100F.

Base Steel	Weight Loss—Mg./7 Sq. In.	
	Steel	Tin
A (Good Service Life)	9.3	13.3
B (Poor Service Life)	28.4	5.2
B (Surface Removed) (0.6% of total specimen weight)	8.7	14.3

When the rate of pickling test is applied to a group of closely related tin plates, such as those in Figure 3, in which all other factors are the same, indication of an intimate relationship between pickle lag and service life is usually obtained. For a large number of unrelated lots of tin plate the line of least squares shows the same trend but the correlation diagram (Figure 4) exhibits considerably more scatter. This is not thought particularly surprising, considering that 1) the pickle lag property is only one of many factors determining the corrosion resistance of tin plate and, 2) the materials included in Figure 4[3] represent plate produced at a total of eight tin mills during a four-year period. (In addition to the limitations of steel composition and tin coating weight, the tin plates represented in Figures 3 and 4 also have been restricted with respect to iron solution value, all lots falling in the 0-20 range. This characteristic and its significance will be discussed in a later section.) Some other factors contributing to the spread in results will be mentioned later.

Examination of steel samples taken after the various stages in tin plate manufacture showed that the pickle lag phenomenon arose in the box annealing operation. It has been found that the condition penetrates the surface layers of metal to varying depths but generally to not more than 30 or 40 millionths of an inch. There is no visual evidence betraying its existence and even steels with very high lags appear bright. As might be expected from the nature of the box annealing operation the occurrence of the pickle lag effect is subject to considerable variation. In 1945, uniformly high values were commonly found on all surfaces of a coil and much less often, uniformly low values occurred. It was found frequently that a coil exhibited mixed behavior, with the outer wraps tending to show lower pickle lag values than the innermost. Particularly prevalent was a condi-

[3] Pack test results shown in all figures and tables in this paper except Figure 1 were obtained with No. 50 tin coatings which were used because the results from experimental packs could be obtained more quickly. Experience has shown the behavior of the lighter coated plates may be extrapolated to the heavier which are of principal commercial interest in replacing hot dipped plate. The steel in all instances was of Type L composition which is a low metalloid, low residual metal grade employed in the container industry where maximum corrosion resistance is needed.

tion wherein high pickle lag values were found on the six or eight inches next to the edges of the annealed coil with virtually none on the rest of the surface.

Once present, the pickle lag is not affected by any of the conventional cleaning, pickling, fluxing, or tinning operations at the mill; neither is it altered by subsequent stripping of the tin coating or alloy by any of the usual methods which do not attack the base steel. Cathodic cleaning or powerful chemical reducing agents including fused sodium hydride-sodium hydroxide have no effect. As already indicated by Table 1, the lag can be removed by acid dissolution of the surface layers of metal and abrading and polishing to a sufficient depth will accomplish the same result.

The only known method for removing the pickle lag without removing the surface layer of metal is by exposure of the surface to suitable atmospheres during heat treatment, dry hydrogen being particularly effective. The time required naturally depends on the thickness affected, but at 1100 F the reaction is relatively slow and requires about one hour for a 40-50 second lag. Above 1200 F only a few minutes are required. Figure 5 shows rate of pickling curves for steel from various areas of the same sheets before and after laboratory reannealing in dry hydrogen. Test packs of containers made from laboratory plated panels of such materials confirm the expected change in corrosion properties. In tin plate made from the steel in Figure 5, for example, cans representing Curve 3 gave 70 percent better corrosion performance in prune pack tests than those representing Curve 1.

The removal of the pickle lag by dry hydrogen suggests that oxidation is in some way responsible for its occurrence and it is possible to produce it by exposure of the surface during annealing to gases more oxidizing in nature, such as hydrogen containing small amounts of water vapor, oxygen, carbon dioxide or carbon monoxide as well as other gas mixtures. Nevertheless the apparent thermodynamic relationships of the particular mixtures suggest they are still reducing to iron and the steels so annealed show no superficial signs of oxidation, being bright, shiny and otherwise perfectly acceptable from the viewpoint of appearance. There does not seem to be any practical limitation on laboratory development of the pickle lag effect and values of 200 seconds have been readily produced. Figure 6 illustrates the results of typical experiments in which the principal point of interest is the ability to produce a high pickle lag (Curve 2) and remove it (Curve 4), thereby obtaining the same result as if originally annealed in dry hydrogen (Curve 3). The significance of these effects can be substantiated by tin-iron couple tests. Of nearly equal interest is the result of incomplete reduction of the pickle lag (Curve 5).

In spite of this, there seems to be more to the development of the pickle lag effect than the oxidizing nature of the atmosphere. For example, it was found that steels annealed in a rapidly flowing current of oxygen-free nitrogen usually develop a lag even at temperatures over 1200 F but are free of this effect at a low flow rate, particularly as stagnant conditions are approached. However, even under conditions more protected from the atmosphere, such as the interior areas of tightly clamped half-inch packs of 6 by 6-inch steel panels, a pickle lag condition develops on the surface if the annealing is for a short period of time at temperatures in the lower range of those employed commercially for tin plate. From these considerations it appears that the well known ability of steel to evolve gases during annealing is involved in the formation of the pickle lag condition. It should also be said that the composition of the steel affects the ease with which the pickle lag factor can be produced.

There has been considerable speculation over the exact nature of the condition responsible for pickle lag and the principal theories may be said to concern a) decarburization, b) a uniformly affected surface layer, and c) grain boundary oxidation. Such data as in Figure 6 and the ability to produce such effects repeatedly in the same sample seems to rule out a). In addition, similar results have been obtained in steel decarburized to .012 percent carbon. No evidence has been secured to support b), but Koehler[8] has reported that some annealing atmospheres which are not oxidizing to ferrite grains are oxidizing to grain boundaries and that the determination of pickle lag is in effect a test for the presence of grain boundary oxides. His paper contains photomicrographs of this condition and an explanation of the mechanism of the pickle lag effect.

Regardless of the exact nature of the phenomenon the results of laboratory annealing experiments permit several inferences regarding the occurrence of pickle lag on commercially produced tin plate. There seems to be, for example, little question that steels showing this condition over all portions of the coil are under-annealed with respect to pickle lag even though grain development is satisfactory by customary standards and the expected hardness obtained. High pickle lag values only at the edges apparently result from exposure of these areas to an undesirable atmosphere during an annealing cycle effective enough to cause clearing of the condition from the more protected areas by evolution of reducing gases from the steel itself. Steels showing uniformly low pickle lags result from a satisfactory combination of annealing gas and cycle.

It should be said that for several years the rate of pickling test has been used as a guide to the development of more suitable annealing practices and as a control on commercial production. Nearly all tin plate suppliers have spent large sums of money for the changes necessary to produce steel with reasonably low pickle lag values. The resulting improvement in corrosion resistance has done much to make heavily coated electrolytic plate a practicable material for plain cans.

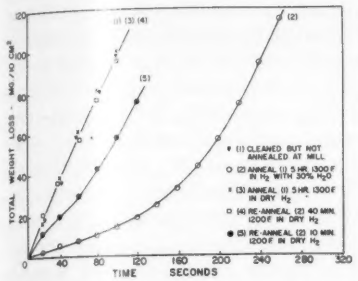
TOTAL WEIGHT LOSS - MG/10 DM²
TIME SECONDS
(1) CLEANED BUT NOT ANNEALED AT MILL
(2) ANNEAL (1) 5 HR. 1300 F IN H2 WITH 30% H2O
(3) ANNEAL (1) 5 HR. 1300 F IN DRY H2
(4) RE-ANNEAL (2) 40 MIN. 1200 F IN DRY H2
(5) RE-ANNEAL (2) 10 MIN. 1200 F IN DRY H2

Figure 6—Rate of pickling tests on steel panels after laboratory annealing and re-annealing in various atmospheres.

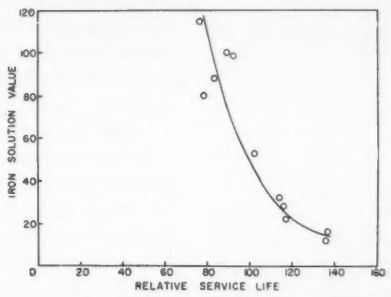

Figure 7—Relationship between iron solution value and service life on tin plates made from same heat of steel. All pickle lag values between 25 and 35 seconds. Test pack medium: Prunes at 100 F storage.

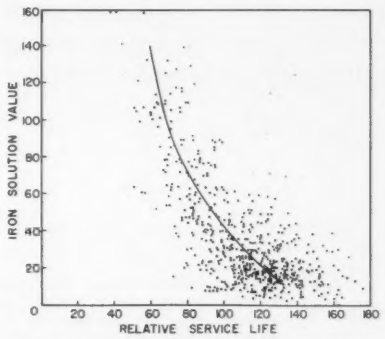

Figure 8—Relationship between iron solution value and service life of tin plates of varied origin. All pickle lag values between 0-10 seconds. Test pack medium: Prunes at 100 F storage.

The "Iron Solution" Test

Early in the application of the rate of pickling test, samples of tin plate were encountered which possessed low lag values but nevertheless exhibited poor service life. This, plus the known fact that variations in corrosion resistance of electrolytic plate were greater than in hot dipped despite the presence of the pickle lag condition to the same degree on both, led to the supposition that other surface characteristics of a more subtle nature existed. Presumably these were carried through to the finished electrolytic plate in greater degree because the preparation procedures were not always as effective as the pickling and fluxing unique to the hot dipping method.

In this connection, it should be stated that the electrochemical protection which the tin affords is never perfect and a certain amount of local cell action at the exposed areas of steel always occurs. It was felt that the nature of the steel surface as affected by the pre-plating treatment determined to an appreciable extent the amount of iron corroded as a result of local action in spite of the generally cathodic nature of these exposed steel areas on the finished product. This suggested that some quick measure of the effectiveness with which tin suppressed local action on the steel was needed.

Such older tests for tin plate quality as the hydrogen evolution test,[9] performed in 1 N hydrochloric acid in which tin is strongly anodic to iron, had previously failed to reflect the degree of shelf life variation shown by experimental packs. In addition, porosity tests, wherein tin is always strongly cathodic, had shown no significant correlation with internal corrosion resistance. It seemed a fair inference that the need was for testing conditions lying between the two extremes. The potential relationships of tin and steel in hydrochloric acid solutions, for example, depend on the concentration,[2] reversing with respect to each other at about 0.2 N. In 0.4 N acid, which is sufficient to make tin anodic to steel but much less so than in the hydrogen evolution test, differences correlated with test pack performance but only in an excessive length of time. A more practical test was found to be a sulfuric acid modification of the acetic acid-thiocyanate-peroxide solution used by Kerr[10] for porosity testing. The modified composition apparently makes tin slightly anodic to steel, in contrast to the Kerr solution and the standardized procedure which has been developed is known as the "iron solution test." Details are given in Appendix B, but briefly it measures in micrograms the total amount of iron dissolved when 3 sq. in. of tin plate surface are exposed to 50 ml of test solution for two hours at 80 F. The unit of measure is arbitrarily called the ISV (Iron Solution Value) and most lots of electrolytic tin plate have ISV's between 0 and 80, but occasionally some are as high as 200.

Excellent correlations between container shelf life and the ISV appear when as many tin plate variables as possible can be excluded. In Figure 7, for example, where the various tin plate lots were from the same heat given the same annealing cycle and plated on the same type of equipment at one mill, and the comparison restricted to plate with a ten second pickle lag range, the results leave no doubt of satisfactory relationship between test and pack results. In common with pickle lag correlations the scatter in results becomes greater, as shown in Figure 8, when the range of samples tested is expanded to include the product of a number of mills with varying types of equipment over a period of several years.

There has been no evidence obtained on the exact nature of the conditions which are responsible for the varying results obtained in the iron solution test. Unpublished reports indicate it is possible to vary the ISV obtained on tin plate from an individual electroplating installation by adjustment of line conditions. It is also recognized that the product of certain lines has consistently lower ISV than others. This last result is obtained even when portions of the same coil are used on each. The difference is apparently related either to inherent characteristics of the equipment or to its operation. Both observations could be explained on the basis of a surface condition which presumably is capable of control by proper pre-plating procedures. The extent to which surface preparation can influence corrosion performance is indicated by Table 2 which contains the results of an experiment wherein part of a coil

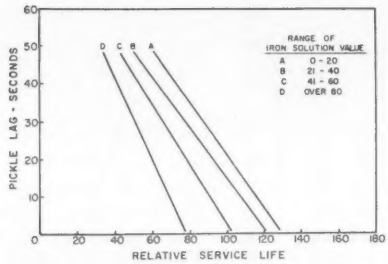

Figure 9—Lines of least squares showing relationship between pickle lag and service life for various ranges of iron solution values. Range 61-80 omitted because of insufficient number of samples.

was "pickled" with hot water in the pickling tank while the remainder was subjected to the usual sulfuric acid treatment. It is important to note that in both instances the finished tin plate was entirely acceptable in appearance, an important commercial criterion of quality, indicating the inadequacy of visual standards for judging corrosion performance.

Combined Effects

It has been demonstrated that both pickle lag and iron solution values are individually related to the corrosion performance of plain electrolytic plate and consequently it is apparent that in any attempt to predict performance both factors must be considered. In order to summarize their combined influence it is necessary to present a family of curves such as in Figure 9, wherein pickle lag is plotted against performance for samples having arbitrarily selected ranges of iron solution values. The curves shown are the least squares lines from Figure 4 and a series of three additional charts with similar data. For successively higher ISV ranges the trend line is displaced further to the left, that is, toward poorer pack performance. The coefficients of correlation calculated for each of the four scatter diagrams are given in Table 3.

Other Factors Influencing Correlation

It has been indicated previously that when the number of known variations in the character of the samples is reduced to a minimum, the correlation of either pickle lag or iron solution values with performance is considerably improved. This is readily apparent from a comparison of Figure 3 with 4 and Figure 7 with 8 and is not explainable on the basis of existing knowledge regarding tin coating, steel composition, structure, nor any measurable tin plate characteristic. Consequently, it is considered there are other less well defined tin plate properties important to the corrosion performance of plain electrolytic tin plate for food products and there are two indications from this work which deserve mention because they are known to account for some of the scatter noted in Figures 4 and 8.

The first factor apparently involves what might be termed effectiveness of anneal. On occasion it was found possible to obtain data such as that in Table 4 which show that even with low pickle lag and iron solution values there can be substantial variation in corrosion performance with the parts of the coil receiving the most heat showing the best results. Because the heating of these coils was entirely from their outside surfaces it might be conjectured the inside portions were underannealed. While this is undoubtedly true from the corrosion standpoint, the inner wraps showed no indication of the hardness or structural differences customarily found in many previously known instances where inadequate annealing affected performance. Variations of the degree shown in Table 4 have not been found in a number of years but a less marked tendency is not unknown today in box annealed plate. It seems apparent that a test for this characteristic, which may or may not involve the steel surface alone, is needed if the corrosion performance of electrolytic plate is to be predicted more accurately.

The second factor known to contribute to the scatter in Figures 4 and 8 evidently is entirely a surface phenomenon. It is known, for example, that identical steels can be made into tin plate on two types of electroplating installations and although the finished products from both have low pickle lag and iron solution values, they still exhibit appreciable differences in shelf life. Typical results with prune

TABLE 2

Influence of pre-plating treatment on ISV and service life with prunes at 100F.

	Iron Solution Values	Service Life, Days
Hot Water "Pickle"	200	21
Regular Acid Pickle	6	134

TABLE 3

Correlation coefficient (r) between pickle lag and service life for indicated ISV ranges—See Figure 9.

ISV Range	No. of Lots Tested	r
0–20	283	.75
21–40	300	.63
41–60	135	.56
61–80	...*	..
Over 80	180	.50

* Insufficient Data.

TABLE 4

Variation in Service Life in coil regions reflecting differences in effectiveness of anneal. Prunes at 100F.

	Service Life—Days	
	Coil 1	Coil 2
Outside Coil Wraps	114	130
Middle Coil Wraps	94	92
Inside Coil Wraps	62	84

TABLE 5

Service Life variation resulting from type of plating installation using steels from same heat handled identically through temper rolling.

	Pickle Lag	ISV	Service Life—Days
Plating System X	4	7	107
Plating System Y	5	3	137

packs stored at 100 F appear in Table 5. The performance variation here is roughly 30 percent but in similar comparisons with prunes stored at average warehouse temperatures (70 F) or with certain other food products the difference can approach 100 percent. The reason for this dissimilarity in the corrosion performance of plate from certain installations, which is quite consistent, is also not understood. It is considered fairly certain that it results from a steel surface condition similar to that measured by the iron solution test and may well be the same factor in a degree the test is insufficiently sensitive to measure. There is reason to believe this difference arises in good part from pre-plating operations, but regardless of its origin it will be apparent that the full potential of electrolytic plate for plain cans will not be realized until this characteristic can be controlled satisfactorily.

Summary

In the preceding sections the following points have been demonstrated:

1. A steel surface condition, called the "pickle lag" effect, arises in the annealing operation and is measured by the "rate of pickling" test. Results of this test correlate well with actual corrosion performance of tin plate containers.
2. The effect of a second surface condition, thought to be governed principally by the preparation of the steel strip immediately prior to electrotinning, is measured by the "iron solution test". Results of this test also correlate with performance.
3. Any attempt to predict the internal corrosion performance of electrolytic tin plate for plain container applications must take into account the combined effect of both pickle lag and iron solution value.
4. Other factors, for which adequate tests do not yet exist, must be understood and controlled if electrolytic tin plate is to be developed to the point desired by the container industry.

In conclusion, it should be noted that tin plate producers have effected control of the factors detected by the rate of pickling and iron solution tests to the degree that heavily coated electrolytic tin plate has replaced a large portion of hot dipped plate for those products requiring the thicker coatings of tin.

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APPENDIX A

Rate of Pickling Test

In principle the rate of pickling test involves only the immersion of a test specimen of any suitable size in 6 N HCl at 90 C and measuring the rate of attack in a convenient manner. The simplest method of testing, that of weighing, pickling for standard time intervals and reweighing is cumbersome when large numbers of specimens are to be run. This led to the development of an instrument known as the "Autographic Pickling Rate Tester"(a) which draws the rate of pickling curve automatically. The apparatus is activated by the hydrogen pressure developed from an 8 x 65 mm specimen dropped into a closed 125 ml vessel of acid provided with a 30 ml headspace.

The acid concentration has an influence on lag value and should be controlled. For example, a change of 0.1 equivalent causes a 1 second difference on a sample with a 23 second lag. The solution should be changed in the automatic instrument after running 10 samples. It is best to standardize on one manufacturer's acid because some differences among brands has been observed. It is necessary to avoid contact between acid and rubber at any time because increased lag values result.

Temperature control is essential in order to produce consistent values. The temperature coefficient with the 23 second lag steel was 2 seconds/1 degree C.

No preparation is required for untinned steel other than degreasing by the usual methods. The coating is removed from tin plate specimens by the "Clarke Method" (antimony trichloride) and they are immersed for 30 seconds in 10 percent sodium hydroxide at 90 C to which enough hydrogen peroxide is periodically added to maintain oxygen evolution. This treatment removes trace residues on the surface which may produce false high results. It is important to avoid fingerprinting which will also produce the same result on certain steels sensitive to this contamination.

APPENDIX B

The Iron Solution Test

Before testing, flat 4 sq. in. discs of tin plate are cathodically cleaned in 0.5 percent sodium carbonate using a 1.5 ampere current for 30 seconds, rinsed in water and dried in acetone vapor. The specimens are placed inside the Bakelite caps from 8 oz. tall form wide mouth bottles and held in place with 2-inch inside diameter gaskets of Tygon No. 3400 1/16-inch thick.

The test is made by adding successively to the bottle 23 ml of 2.18 N sulfuric acid, 2 ml of 3 percent hydrogen peroxide, prepared from the 30 percent grade, and 25 ml of a 40 g/l solution of ammonium thiocyanate. For convenience a stock solution of the first two ingredients, which is stable for several weeks, may be preferred. The cap with the specimen is screwed on tightly, the assembly is inverted and allowed to stand two hours at 80 F without agitation. At the conclusion of this period the vessel is placed upright, cap with specimen is quickly removed and 1 ml of 3 percent hydrogen peroxide is added. The total iron content in micrograms is determined directly in the solution using a spectrophotometer set at 485 millimicrons.

Caution: Small amounts of hydrogen cyanide are formed during the test so the bottles should be opened and the analysis made under a hood.

DISCUSSIONS

Discussion by H. H. Uhlig, Massachusetts Institute of Technology, Cambridge:

This useful summary of a complex subject points to the need for a few additional basic data in order to satisfactorily explain general corrosion behavior of tinplate in test media used so far. Important among such data are microchemical analyses of surface concentrations of elements like sulfur, phosphorus and

(a) Obtainable from Thwing-Albert Instrument Company, Penn Street and Pulaski Avenue, Philadelphia 44, Pennsylvania.

arsenic, known from other studies to have a marked effect on the acid attack on steel. Are analyses of this kind, difficult though it is to obtain them, being carried out, and also what is the effect on vacuum anneal?

Reply by A. R. Willey:

The Type L steels used in the present study had low overall sulfur, phosphorus and arsenic contents. We have made no study of surface concentrations of these elements, especially with respect to correlation with the phenomena reported in the paper.

Results of annealing full hard Type L tinplate steels in vacuum were somewhat contradictory but in general fit the following pattern: Specimens heated in a small vessel continuously pumped during the anneal developed "lag" condition. Samples in a similar vessel sealed off after evacuating so that gases evolved from the steel during annealing provided the atmosphere, showed no "lag". These observations paralleled those reported for annealing in rapidly flowing and stagnant nitrogen atmospheres.

Any discussions of this article not published above will appear in the December, 1956 issue.

Part 1 of 2 Parts

Aqueous Corrosion of Aluminum*

Part 1—Behavior of 1100 Alloy

By J. E. DRALEY and W. E. RUTHER**

Abstract

Aluminum alloy 1100 corrodes uniformly in nearly pure water at rates which increase with temperature. The reaction is characterized by an initial period of relatively rapid corrosion, followed by a constant lower rate of corrosion. The slope of the linear part of the curve or the "corrosion rate" changes from about 0.02 to 2.5 mg/dm²-day (.01 to 1.3 mil/yr) from 50 to 200 C. Above 200 C intergranular attack occurs, with resultant more rapid penetration and deterioration of the metal.

The corrosion rate can be reduced by the addition of an acid to the water. The solution pH of minimum corrosive attack on aluminum goes down with increasing temperature. It is of the order of 6.5 at 50 C and 3 at 300 C.

Corrosion in slightly alkaline solutions (pH 8.5) is more rapid than in neutral water at all temperatures. At 100 C the difference shown in stagnant tests is very slight, but increases considerably if the temperature is increased to the order of 200 C. Presumably the effect of solution flow rate would be greater in the case of alkaline water than in neutral water.

At 200 C the addition of dichromate ion increased the rate of corrosion. A small concentration of sodium silicate resulted in a higher corrosion rate at pH 9.4, while at pH 3.5 it reduced the rate significantly. Chloride ion (5 ppm) caused some pitting and increased the corrosion rate slightly.

Electrical coupling to more cathodic materials, such as graphite, zirconium or stainless steel produced no undesirable effects in distilled water at 200 C. At 315 C, the corrosion life of samples was extended by such coupling. **6.4.2**

Introduction

THERE HAS BEEN increasing demand for metals which can withstand the corrosive effects of coolants at high temperatures. Water is a coolant with obvious advantages and aluminum has been shown to be satisfactory for use in aqueous environments at temperatures below the boiling point. A number of references summarize its corrosion characteristics.[1-5]

There are no known references which give actual corrosion rates at low temperatures (< 100 C) for aluminum in distilled water or water of comparable purity. In most open literature publications the corrosion of aluminum in such media is described as "ceasing" after an initial period of moderate reaction rate. Information in Reference 3 is about the closest known to published corrosion rates for aluminum in nearly pure water.

For some time it seems to have been customary in many places to assume that the use of aluminum as a material of good corrosion resistance to water and aqueous solutions should be restricted to moderate temperatures. This assumption has probably had its basis on results of a few exploratory tests which have shown poor corrosion resistance for aluminum at high temperatures. However, aluminum alloys have been used as pistons for service in super-heated steam up to 400 C in European countries. Guillet and Ballay[6] have reported some experiments performed with superheated steam in the 300 and 350 C range. The metal did not corrode badly except in the case of some very pure metal which disintegrated completely. Their work, and some by others[1] seems to indicate that a minimum silicon content in aluminum is required to maintain corrosion resistance. Grube and Eastwood,[7] have described tests in distilled water at elevated temperatures on commercial aluminum alloys and specially prepared alloys containing 6 percent magnesium. They found that, as compared with 1100 (formerly 2S) aluminum, most common alloying elements do not markedly increase the corrosion resistance in water at 315 C. Corrosion rates observed at this temperature were rapid but not catastrophic.

In a series of memoranda Goldowski[8] reported average weight gains of about 0.3 mg/cm² for 16 hours' exposure to distilled water up to 274 C in Pyrex equipment, but did not call this attack corrosion, apparently reserving this term for the rapid dissolution of the metal. Above 275 C, she observed complete disintegration of the samples. Another series of experiments showed a considerable dependence of corrosion in distilled water at 200 C on the amount of silica present in the system. However, the various samples of metal behaved so differently as to reduce greatly the reliability of the results. On the basis of a few short time experiments at 200 C, conclusions were drawn as to the values of certain corrosion inhibitors, such as chromic and boric acids alone and in combinations with sodium silicate solutions. Tests have been run by Link[9] in high purity distilled water at temperatures up to 150 C. The water flow rate was about 25 ft/sec. past the samples. Actual weights of metal corroded were not determined due to the difficulty of removing the corrosion product, but the weight gains were relatively small and the sample appearance very good.

Earlier publications by this group,[10] by Strom, Boyer, and Litz,[11,12] and by Huddle and Wilkins[13] contain the only known reported corrosion rates of 1100 aluminum for temperatures significantly above the boiling point of water.

★ Submitted for publication January 16, 1956.

* Argonne National Laboratory, Lemont, Ill.

The work described here has largely been reported in Argonne National Laboratory reports (ANL-5001 & ANL-5500). Although these reports are available upon request, most of the information is reported here in order to make it readily available.

Experimental Procedures

All samples were cut from one sheet of 16 gauge 1100 aluminum. The specimens were ¾ by 3-inch in dimensions with a $\frac{3}{32}$-inch hole near one end. All samples were annealed before use. Analyses of the metal indicated 0.52 percent Fe, 0.13 percent Si, 0.12 percent Cu and 0.01 percent Ti. All other normal metals were below spectroscopic detection limits.

A fresh uniform surface was prepared by wet grinding with 400 grit Durite abrasive paper on a metallographic polishing wheel. Under microscopic examination no abrasive particles were visible on the metal surface. Samples showing inclusions were discarded. Specimens then were measured, degreased in freshly distilled ethyl alcohol and weighed on an analytical balance.

Tests at elevated temperatures were run in two kinds of apparatus. In the first, the only type used at the highest temperatures, stainless steel autoclaves (volume 175 ml) were about three-quarters filled with water or solution and placed in ovens to maintain the desired temperature. Each time an autoclave was opened for sample examination the water or solution was changed. This type of test was called a stagnant test. In other systems, water or fresh solution was stored at temperature in a stainless steel tank. The solution was allowed to flow through the thermostated test autoclave to the atmosphere through a controlled leak. These were called refreshed systems. The test chambers contained about 200 ml of solution. Rates of addition of fresh water or solution were of the order of 2 cc/min. In these tests, water composition remained reasonably constant throughout the test periods and without significant contamination by the samples.

Samples were suspended in the stagnant tests by 1100 aluminum wire, using a mica washer in the gas phase to insulate electrically from the stainless steel. In the flow system Teflon racks were used.

Duration of most tests above the boiling point was roughly 20 days, since this was sufficient to determine the "corrosion rate" after the initial period of reaction.

Tests at temperatures below 100 degrees were made in closed Pyrex chambers to which fresh solution was added continuously. All solutions were made up using reagent grade chemicals and double distilled water. Quality control tests of incoming and effluent solutions were made using a pH meter, resistivity bridge and, where required, a spectrophotometer for colorimetric analysis.

For tests at temperatures above 100 degrees the autoclaves or test chambers were heated to boil the water vigorously, at which time they were closed. In this fashion tests were run in essentially degassed water. Samples were removed periodically from tests, dried in a vacuum desiccator, weighed, and replaced in test. At the end of the test the procedure was repeated, followed by removal of the corrosion product by a cathodic treatment in a hot solution containing 4 percent CrO_3 and 10 percent H_3PO_4 (by weight). This treatment effectively removed the corrosion product, but did not significantly attack the underlying metal. At temperatures above about 150 C the corrosion product was not adequately removed by the cathodic chromic-phosphoric treatment. In these cases, samples were made the anode by several hundred volts in a saturated boric acid solution at room temperature for several minutes. Following this violent treatment the standard chromic phosphoric mixture removed the corrosion product adequately. Clean sample runs indicated a loss of 0.06 mg/cm² for the overall process.

For high temperature tests, weighings allowed determination of total metal corroded and coat weights at the end of each test. Temporarily assuming that none of the corrosion product was lost, its composition was assumed to be $Al_2O_3 \cdot XH_2O$, and the value of X was calculated. Since it was determined by X-ray diffraction that the actual composition of the corrosion product was $Al_2O_3 \cdot H_2O$, deviations of the calculated values of X from 1 were presumed to be caused by the loss of corrosion product to the solution. Values of X at various times throughout the tests were estimated by assuming that at zero test time X equalled 1 and changed linearly until the end of the test, at which time its value was determined. Using these values of X, the amount of metal corroded at each weighing period was computed, corresponding to the weight gains of the samples at the same times.

At temperatures below 100 degrees, a somewhat more rigorous treatment was found necessary. In these cases two samples were removed permanently from test at each weighing period and X computed. These individually determined values of X were then plotted as a function of time to give somewhat more reliable values for this number. In all cases the values for the amount of metal corroded were then plotted as a function of time. A straight line usually represented quite well the corrosion which followed the first few days of exposure. The slope of this straight line is called the "corrosion rate."

In order to avoid the scattering normally experienced in plotting amount of metal corroded for individual samples, the weight changes of the samples before removal of corrosion product were averaged for all samples in test. For the first time interval there were available as many sample weight changes (computed per unit area) as there were samples. For the second exposure period the average change in weight which had occurred since the last weighing was determined and added to the first point. These special average points then were corrected as indicated by the determined values of X to yield the average amount of metal corroded per square centimeter of sample surface.

This special method of averaging test data was required for the low temperature corrosion rate determinations because of the very low rates sometimes

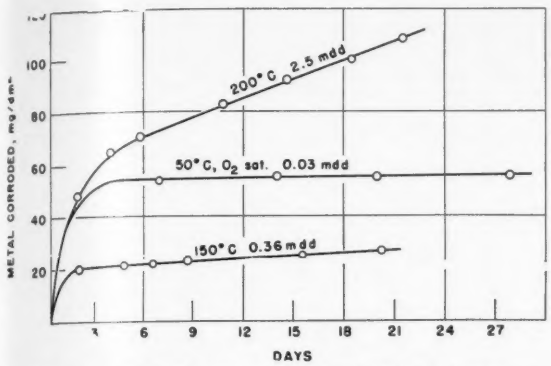


Figure 1—Corrosion of aluminum alloy 1100 in distilled water.

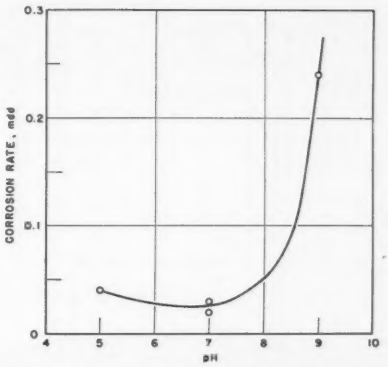


Figure 2—Corrosion of aluminum 1100 in oxygen-saturated solutions at 50 C.

observed. A corrosion rate of 0.05 mdd (milligrams per square decimeter per day) corresponds to an amount of metal corroded of 0.1 milligram per week for the 30 cm² samples used. The procedure gives reliable rates so long as individual samples can be expected to corrode at approximately the same rate after the first few days, even though the amount of corrosion occurring during the initial period is different from sample to sample. Experimentally it has been inferred that this is true since the weight changes of samples form such a series of parallel curves.

Data

By observation under a microscope, the corrosion product formed on 1100 aluminum in relatively pure water characteristically takes the form of a two-layered film. The inner layer is thin and quite protective. Corrosion proceeds through this film, or through breaks or imperfections in it. The reaction does not seem to be uniform because microscopic examination shows evidence that the film has breaks in it, and is not uniform in thickness, (additional evidence: typical interference colors are not exhibited). Also after corrosion the metal surface is characteristically pock-marked or etched in appearance. During corrosion, the average thickness of this film builds up for the initial reaction period, then apparently remains constant, as evidenced by the essentially constant corrosion rate observed.

As this film is continuously formed it continuously (but not necessarily uniformly) breaks loose or recrystallizes to form the much thicker white or gray corrosion product layer on the outside. This layer appears porous and apparently does not control the rate of corrosion, because the rate does not change as the layer grows thicker.

Behavior is illustrated in Figure 1 where the amount of metal corroded is shown as a function of time for 1100 aluminum. Factors influencing the height of the first part of the curve, or the intercept of the straight line portion, are not particularly well understood and are being studied at present. It is true that in unbuffered distilled water the amount of metal corroded during this initial part of the reaction is very much greater than that required to produce the thin protective barrier layer of oxide. The most consistent effect is the increase in this amount of corrosion as the pH is increased.

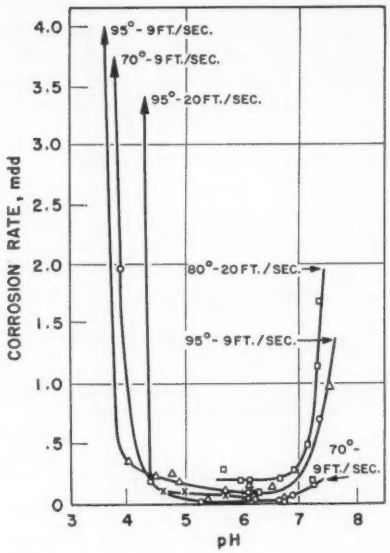
Low Temperature Tests

Effect of solution pH is illustrated in Figure 2. Corrosion rates (slopes of straight line portions) are plotted as a function of the pH (measured at room temperature) of nearly pure water or unbuffered H_2SO_4 or KOH solution. It will be observed that an increased corrosion rate resulted at pH 9. The minimum rate appears to be at a pH between 5 and 7, but it could be that the small difference observed between pH 5 and 7 is not significant. This is qualitatively a corroboration of the effect of pH on the corrosion of aluminum in slightly more concentrated solutions with solution flow rates past the metal of 9 to 20 ft/sec. Figure 3 is reproduced from reference.[3] A rather broad range of low corrosion rate is exhibited, with the minimum in the neighborhood of pH 6.5. Where the solution was either more acid or more alkaline than the broad central region, sharp increases in rate occurred with changing pH.

At pH 7 and above, increasing the temperature from 70 to 95 C (at 9 ft/sec. flow rate) caused increased corrosion rates. In spite of this fact, higher rates resulted from lowering the temperature to 80 degrees and increasing the flow rate to 20 ft/sec. This supports the deduction that there is a strong dependence of corrosion rate on solution flow rate in this pH region.

The same strong dependence on flow rate is exhibited in the pH range from 4 to 4.5 (at 95 C). In this region, however, there is an inverse dependence of corrosion rate on temperature (at 9 ft/sec.). This factor apparently holds up to considerably higher temperatures as well, making it possible to have the pH of minimum attack be as low as 3 at temperatures above 200 C (see later).

The corrosion rate of 1100 aluminum can be reduced below that observed in water by the addition of certain oxidizing agents such as dilute hydrogen peroxide or dilute dichromate. For example, the rate obtained in 70 C helium saturated water was 0.07 mdd. The rate was reduced to 0.04 mdd in 10^{-3} N hydrogen peroxide solution at this temperature. Simi-



Solutions air saturated. Most contained H_2O_2 ($1 - 10 \times 10^{-5}$N), $CaSO_4$ (68 ppm), $MgSO_4$ (30 ppm), NaCl (1-2 ppm); some were in distilled water. pH (@ RT) was adjusted with H_2SO_4 or NaOH.

Figure 3—Effect of pH and other variables on aqueous corrosion of 1100 aluminum.[3]

TABLE 1—Summary of Corrosion Data for 1100 Aluminum from 100 to 200 C Refreshed Tests, Solutions Degassed

Temperature, Deg. C.	pH	Slope (Corrosion Rate), mg/dm²/day	Intercept, mg/dm²
100	7	0.29 (inaccurately determined)	21
125	5	0.06	21
	7	0.10	13
	8.5	0.58	27
150	5	0.13	16
	7	0.36	20
	8.5	0.87	27
175	5	0.34	18
	7	0.88	18
	8.5	1.3	37
200	5	1.4	21
	7	2.5	54
	8.5	7.6 (6 to 17 dxys)	25

lar tests using small amounts of dichromate ion (2 ppm $K_2Cr_2O_7$; pH controlled at 5.0) resulted in corrosion rates too small to be measured to the degree of sensitivity of the present techniques. Oxygen-saturation apparently does not provide sufficient oxidizing potential to cause much change, since the corrosion rate determined in O_2-saturated distilled water was also 0.07 mdd.

Elevated Temperature Tests

Table 1 presents the test results obtained with very dilute solutions in the refreshed systems. The adjustment of pH was accomplished with potassium hydroxide or sulfuric acid and the pH measurement was made at room temperature. All samples acquired a moderately thick light grey coating and had corrosion curves similar to the ones shown in Figure 1.

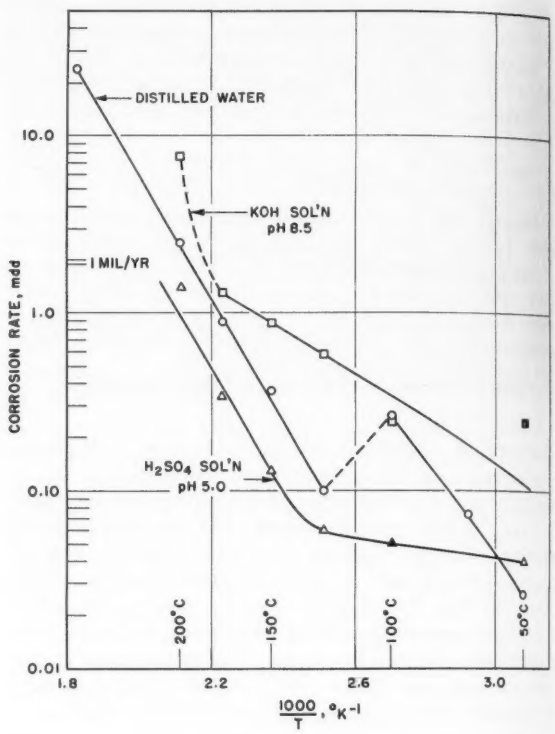


Figure 4—Aqueous corrosion of 1100 aluminum.

On removing the coating after the test, the metal was found to be uniformly etched but with no deep pits.

These values plus averages of several obtained at 70 and 50 C are plotted in Figure 4. Solid points are used where the pH was not the standard value in acid or alkaline solutions. That at 50 degrees, for example, was 9.0. All rates are subject to considerable inaccuracy. At low temperatures the corrosion rates are small and weighing errors for samples which must be corroded and handled cast doubt on determination of the very small slopes of metal corroded versus time curves. At the higher temperatures the weight changes sometimes were difficult to determine because the corrosion product was quite difficult to remove. Also the stainless steel testing systems corroded slightly and it is not known whether the resultant water contamination had significant effect on the aluminum corrosion.

The straight line relationship in water at temperatures above 100 C suggests that the reaction mechanism is the same for this region. The activation energy calculated from the slope for corrosion in distilled water is 16.2 kcal/g-atom. Somewhat lower activation energies are perhaps indicated at the lower temperatures.

The sharp break in the curve of corrosion rate as a function of temperature which occurs below 125 C is probably explained by the change in the composition of the corrosion product. At 90 C and below the corrosion product determined by X-ray diffraction was β $Al_2O_3 \cdot 3H_2O$. Above 100 degrees it was *a*

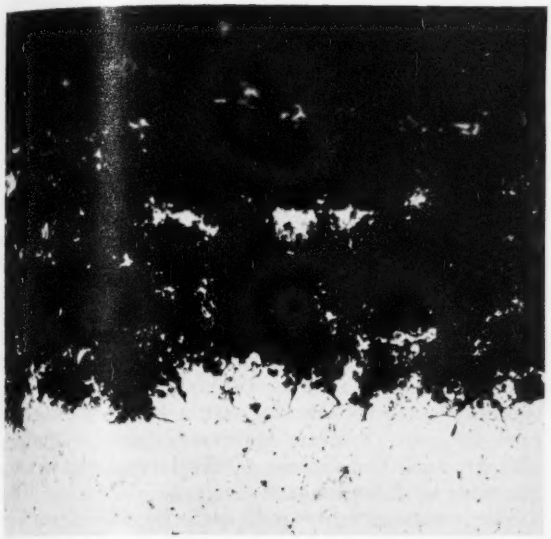


Figure 5—Cross section of 1100 aluminum specimen after eight days in water at 275 C. 100 X

$Al_2O_3 \cdot H_2O$. The temperature at which the transformation in corrosion product takes place is not known any more sharply than this and apparently changes with the purity or composition of the solution in which the metal is corroded.

Between 1 and 8 days at 275 C, corrosion proceeded at the rate shown by the point on the figure. After that, however, the reaction became much more rapid and might be estimated to be 10 or 20 times that indicated in the figure. It was observed that intergranular attack began then and pieces of metal, apparently grains, were undercut by corrosion, as indicated in Figure 5. This was a stagnant test in which samples were removed only after a full exposure period. Samples removed after about seven days generally showed the beginning of similar intergranular attack and concurrently the pH rose to above 8. It was suspected that the increased pH played a role in instigating the attack. Experiments performed in the Argonne Reactor Engineering Division, however, have indicated that the same kind of attack took place in a recirculating system in which the water purity was maintained with an ion exchange resin. In these cases also, severe intergranular attack set in after several days of testing at 288 and 260 C. The flow rate of water past the samples in these tests was about 25 ft/sec. Accurate corrosion rates were not determined and so do not appear in Figure 4, although they were of the same order as those obtained in this investigation prior to the intergranular attack.

The beginnings of the same kind of intergranular attack seemed to occur at 200 C for some samples in a stagnant test at pH 4.5. Characteristic appearance of such samples was as though small blisters were formed here and there on the sample surface. These blisters consisted of a mixture of aluminum metal and aluminum oxide corrosion product. For these samples the corrosion rate did not rise sharply with time after initial exposure, as it did at the higher temperature and it is not certain whether the phenomenon observed would cause rapid deteriorating corrosion on longer exposure. In Figure 6, two curves are given for metal corroded in the stagnant test: One for samples which showed the formation of such blisters and one for those which did not. This behavior perhaps explains the position of the corrosion rate at 200 degrees, pH 5 in Figure 4 (slightly high).

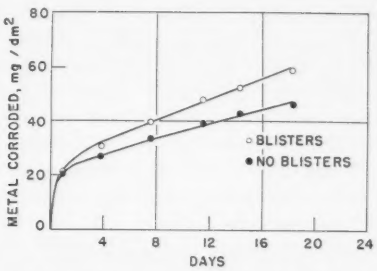


Figure 6—Stagnant test, pH 4.5, 200 C.

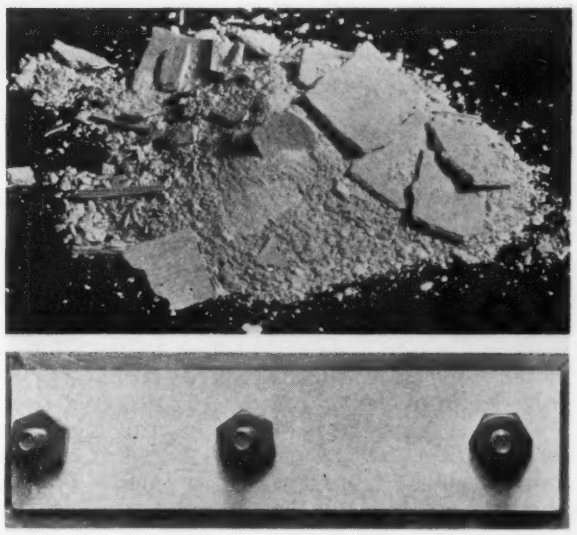


Figure 7—1100 aluminum after four hours in distilled water at 315 C. Top: From uncoupled specimen. Bottom: Coupled to 347 stainless steel.

At 315 C, it was observed that after just a few hours' exposure the metal was consumed completely, resulting in a heap of aluminum oxide on the bottom of the test autoclave. Remnants of one such sample are shown in Figure 7, top. Exposure in this case was four hours. The sample had been a piece of aluminum sheet; it exhibited approximately standard behavior for samples in the most sensitive conditions. It was observed that aluminum gaskets used on some autoclaves for such tests did not disintegrate but showed relatively low corrosion rates only. Because the aluminum was in contact with steam at the elevated temperature it was surprising the gaskets should hold up so much better than the sample submerged in the liquid.

To investigate the phenomenon further, a sample of 1100 aluminum was coupled to a piece of 347 stainless steel, the material of which the autoclaves were made. It was found that after exposure of four hours

the aluminum was corroded very slightly, as illustrated in Figure 7, bottom, and that after 18 hours it was still in fairly good condition. The same protective action was observed when zirconium was used as the cathodic metal in the couple. In both cases current measurements, at temperature, between samples of aluminum and the other metal showed that the metal protecting the aluminum from rapid corrosion was cathodic to it.

Subsequent work has indicated that this unusual case of anodic protection can be explained in terms of damage to the sample produced by the corrosion hydrogen liberated. This subject is discussed in detail in the second paper in this series.

Coupling 1100 aluminum to graphite or zirconium for 39 days in distilled water at 200 C produced no galvanic attack. The coating on the coupled sample of 1100 was slightly more uniform than on the controls: All were in good condition.

Effect of Low pH.

As shown, the data indicate that a slight reduction in pH is desirable. Therefore a test was run to determine if a further reduction in pH would produce a lower rate of corrosion. As shown in Table 2 the reduction in rate is striking. Attack by the solution on the stainless steel autoclave prevented any further reduction in pH for long term tests. However, some preliminary tests were performed in small autoclaves for short times. The results of these tests at 200 and also 250 and 300 C are presented in Table 3. The pH of minimum attack (for short times) is near 3 for the three temperatures tested. To eliminate the possibility that $SO_4^=$ was acting as an inhibitor, the last test in the table was run. When potassium sulfate was added in quantities sufficient to provide a sulfate ion concentration equal to that in pH 3 sulfuric acid, no difference in corrosion from that in distilled water was noted.

Dichromate and Silicate Additions. In many aqueous environments, dichromate and soluble silica have shown good inhibitory action. Potassium dichromate and sodium metasilicate were chosen therefore as possible high temperature inhibitors for investigation at 200 C. The solution pH was controlled by the addition of potassium hydroxide or sulfuric acid. The results of these experiments are summarized in Table 4, with the tests without the possible inhibitors included for reference.

Two features of Table 4 are of interest. First, only a combination of low pH and silica proved beneficial while the dichromate additions actually increased the corrosion rate by a factor of the order of three. (dichromate was not tried at pH below 6.1). Second, at the high rates obtained with neutral and alkaline solutions, the intercept is essentially zero. This is a departure from the usual aluminum behavior.

The use of these common low temperature corrosion inhibitors would obviously be very unwise at 200 C unless pH adjustment was used also.

Chloride Additions. The chloride ion is noted for its tendency to produce pitting and increased corrosion of aluminum in aqueous solutions at ordinary temperatures. A test was performed with a 5 ppm Cl^- solution (KCl) at pH 3.5 (helium saturated) to evaluate this tendency at 200 C. An average of about one pit for every three square centimeters was formed on specimens exposed for 19 days. Pits formed were typically surface channels with a length to breadth ratio of three or more. Maximum depth of the pits was 0.6 mm. Dimensions of the largest pit was 0.6 mm wide by 2 mm long.

The corrosion rate measured for this condition was 1.0 mdd (intercept 18 mg/dm²) as compared with a rate of 0.7 mdd (intercept 21 mg/dm²) for the same conditions except for the chloride. Data indicate that the chloride ion promotes pitting at 200 C, although the effect is apparently somewhat less than at temperatures below 100 C, as judged by some unreported low temperature tests.

Discussion

Effect of Temperature

The change in corrosion rate of 1100 aluminum in distilled water as a function of temperature follows an Arrhenius plot at temperatures of 125 degrees and above, indicating an unchanging corrosion mechanism in this range. At the lower temperatures the phenomena are not well understood but it is known that there is a change in the stable corrosion product, occurring in the general vicinity of 100 degrees in distilled water. Perhaps it is this factor which causes a discontinuous curve of corrosion rate as a function of temperature, with the slope of the curve not much different at 50 to 100 degrees than at 125 to 275 C. It is known by X-ray analysis that the (relatively thick) corrosion product at low temperatures is β $Al_2O_3 \cdot 3H_2O$ and is α $Al_2O_3 \cdot H_2O$ above 125 C. It is not certain this is pertinent, because it is not the relatively thick corrosion product which controls corrosion rate, but rather a thin film of undetermined structure. The temperature at which the transition in the bulk corrosion product takes place seems to be a function of the solution composition. More specific

TABLE 2—Effect of Solution pH on the Corrosion of 1100 Aluminum at 200 C

SOLUTION	pH	Slope mg/dm²/day	Intercept, mg/dm²
Distilled Water	6.5–7.0	2.5	54
H_2SO_4	5.0	1.4	21
H_2SO_4	3.5	0.7	21

TABLE 3—Corrosion of 1100 Aluminum as a Function of pH Aluminum Metal Corroded, mg/cm²

pH (H_2SO_4)	200 Degrees 48 Hours	250 Degrees 20.5 Hours	300 Degrees 6 Hours
2	1.3	0.59	0.51
3	0.16	0.07	0.19
4	0.18	0.36	0.23
5	0.25	0.42	0.36
6.5	0.25	0.47	0.60*
(Distilled)			
6.3	$SO_4^=$ Conc. = (K_2SO_4)	pH 3 H_2SO_4	0.57*

* Calculated from weight gain—Sample could not be effectively stripped due to blisters.

statements as to the dependence of this transition temperature on solution composition cannot be made.

Effect of pH

In specifying the corrosion rate of aluminum as a function of temperature in nearly pure water it is necessary also to specify the pH of the solution. At all temperatures it is true apparently that there is a pH of minimum corrosion. At temperatures below the boiling point of water this pH is in the general vicinity of 6 to 6½ (measured at room temperature). For example, it was noted that a small amount of pitting took place in autoclave tests at 100 C and pH 4.4. Apparently this pH should be specified as slightly too low for adequate resistance to corrosion at this temperature. Increasing pH above that at which minimum attack takes place generally increases the rate of corrosion of the metal and makes it much more susceptible to effects such as solution velocity. Apparently this effect is due to the increasing solubility of the corrosion product in the environment as the pH is increased. The pH of minimum attack thus described apparently goes down as the temperature is increased, so that, for example, the pH of minimum attack at 300 C seems to be about 3, based on scanty evidence. At temperatures intermediate between the boiling point and 300 C it is to be expected that the pH of minimum attack lies between 6 and 3.

The interrelation between temperature and pH very possibly is occasioned by the increased ionization of water with increasing temperature. If, for example, the most serious harmful effect of increasing temperature is the increased concentration of hydroxide ions which result in pure water, then it is understandable that adding acid to reduce the concentration of hydroxide ion would reduce the harmful attack of the metal. Although data are not available at present to make it possible, it would appear desirable to compare corrosion rates of aluminum as a function of temperature in dilute acid solutions at constant hydroxide ion concentration.

Not only does the ionization constant for water increase with increasing temperature, but so does that for a typical weak acid or weak base. Consequently it is to be remembered that acid solutions described here in terms of the pH at room temperature are not equivalent in elevated temperature corrosivity to solutions of weak acids having the same room temperature pH.

Nature of the Attack

In high purity water at temperatures below 200 C, aluminum has exhibited only uniform attack. To the knowledge of the authors there has never been an instance of pitting of aluminum in high purity water. There have been some instances where such localized attack took place in crevices between aluminum and materials cathodic to it, but in these cases it is believed that the quality of the water became poor in the crevice during the test. It is true apparently that while aluminum is corroding it repairs breaks and faults in its protective oxide film as long as water purity is good. At temperatures above 200 C, however, a new phenomenon is observed. It has been known for some time that some samples of aluminum corrode very rapidly in water at high temperatures and form a powdered corrosion product. The present work indicates that this is the result of an intergranular attack which penetrates the metal rapidly and isolates small fragments of metal on which reaction then can proceed. It has been quite difficult to show with certainty whether this penetrating attack is purely intergranular because of the difficulty of showing grain boundaries and penetration on the same photograph. Metallographic examination indicates that in those cases where grain boundaries and the area of penetrating attack can be observed, the attack is taking place at the grain boundaries.

TABLE 4—Effects of Possible Inhibitors on the Corrosion of 1100 Aluminum at 200 C Solutions Deaerated

SOLUTION	Corrosion Rate mg/dm²/day	Intercept, mg/dm²
Distilled Water	2.5	54
H_2SO_4 Sol'n., pH 3.5	0.7	21
KOH Sol'n., pH 8.5	7.6	25
K_2CrO_7 Sol'n., 50 ppm; pH 6.1 (adjusted with KOH)	9	0
K_2CrO_7 Sol'n., 50 ppm; pH 8.4 (KOH)	21	0
Na_2SiO_3 Sol'n., 30 ppm SiO_2; pH 9.4 (H_2SO_4)	10	0
Na_2SiO_3 Sol'n., 30 ppm SiO_2; pH 3.6 (H_2SO_4)	0.2	14

Height of Intercept

As has been noted previously, the amount of corrosion which takes place in the first several days of exposure of aluminum to water and very dilute solutions is considerably greater than that required to produce a film of corrosion product of the type which controls the rate of subsequent corrosion. It is a matter of practical as well as theoretical interest to understand this part of the corrosion reaction. Some factors are apparent. Although solubility of the corrosion product formed on the sample surface is quite low in neutral distilled water, a rather significant amount of aluminum hydroxide is formed in the water in a test chamber during the initial period of the reaction below 100 C. It is suspected that this indicates a higher solubility of the corrosion product in the water immediately adjacent to the sample surface. Because solubility of the corrosion product increases rapidly with increasing pH above neutral, but does not do so with decreasing pH, it is suspected that this is evidence that the solution immediately adjacent to the metal surface is more alkaline than the bulk water. This has been corroborated by measuring the pH adjacent to the rapidly corroding metal, using a tiny hydrogenated palladium electrode. Also, it has been observed that the intercept is significantly greater for corrosion taking place in slightly alkaline solution than in neutral water, which in turn causes a higher intercept than in dilute acid solution. Perhaps the alkalinity in distilled water occurs at certain parts of the sample surface rather than all of it (presumably the cathode areas). In any case, it is known that the pH of distilled water (oxygen-free) is often increased by placing aluminum in it.

Another possible reason for the magnitude of the reaction in the first several days is that the surface

condition of the clean metal as put into test is not necessarily a satisfactory one for supporting and retaining the thin protective film. Both surface working and preferential etching on a microscopic or submicroscopic scale might leave the surface metal atoms so that their configuration is not suitable to allow bonding with and stabilization of the protective film. It is not known whether a certain amount of metal must be dissolved away by corrosion to produce such a favorable surface condition of the metal, or to expose the best crystal faces. A number of experiments in which aluminum has been corroded in potassium sulfate solutions seem to infer that it is important that the initial amount of corrosion take place, whether it be rapid or slow, before the final very low corrosion rate is obtained. In these cases, times ranging from a few weeks to more than six months were required to finish the initial corrosion period. After that time the corrosion rate appeared to be about the same as that in distilled water under the same conditions.

Practical Significance

It appears to be true that aluminum is a material of good corrosion resistance to pure water at temperatures up to about 200 C. It probably could be used with safety as a construction material up to this temperature. Above this temperature the penetrating intergranular attack must be eliminated in order to provide a usable corrosion lifetime. Methods of accomplishing this are described in the second paper in this series.

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End of Part 1

Part 2 Will Be Published in October, 1956 Issue

Any discussions of this article not published above will appear in the December, 1956 issue.

Behavior of 18-8 Stainless Steel In 2 Normal Boiling Nitric and Sulfuric Acid Mixtures*

By P. E. KRYSTOW and M. BALICKI

Introduction

THE AUSTENITIC stainless steels are important materials of construction, because they combine excellent mechanical properties with a high resistance to corrosion.[1] In certain media, however, such as dilute solutions of sulfuric acid, the surface film from which these steels obtain their corrosion resistance is destroyed and as a consequence the stainless steels suffer rapid corrosion. Since it is of considerable practical importance to ascertain the effect of environment on the corrosion resistance of austenitic stainless steels, the behavior of steels exposed to various acid and salt solutions has been extensively studied in laboratories, testing stations and actual service. A survey of such data can be found in the Corrosion Handbook.[2]

An acid mixture commonly employed in many nitrating processes in the chemical industry is one of nitric and sulfuric acids. Handling of nitrating acid mixtures, both strong and dilute, hot or cold, often requires the use of stainless steels. It is well known that austenitic stainless steels corrode rapidly in dilute sulfuric acid while exposure to nitric acid results in almost negligible corrosion. Therefore, it can be expected that increased corrosion resistance will occur with the addition of nitric acid to a dilute sulfuric acid solution. Indeed, such additions are made purposely to minimize corrosion by the sulfuric acid attack.[3] The behavior of austenitic stainless steels in mixtures of nitric and sulfuric acids is not well established[2,3] and it is the purpose of this paper to report some results obtained from studies of corrosion of Type 18-8 stainless steel under these conditions.

Stainless Steel

For this study AISI Type 304 (18 Cr, 8 Ni) steel was used. It was supplied in the form of annealed 0.186-inch thick plate. Spectrographic analysis of this steel revealed its composition to be as shown in Table 1. From this plate, several 2-inch diameter discs with a ¼-inch center hole were machined. As may be seen in the flow sheet of experimental work (Figure 1) such samples were wet ground on a belt surfacer using No. 80 "Durite" cloth and finished by hand on 320 grit "Jewelite" paper.[4] After determining the surface area to an accuracy of ± 0.01 square inch, the samples were cleaned with water and acetone. The discs were weighed immediately after drying and subsequently corrosion tested.

Corrosives

Investigating all possible mixtures of nitric and sulfuric acids was beyond the authors' capacity. It was decided therefore to restrict the work to one acidity level, namely to 2 Normal HNO_3-H_2SO_4 acid mixtures. Carefully analyzed concentrated nitric and sulfuric acids were used to prepare the mixtures. These acids were subsequently diluted with distilled water to 10-Normal concentrations, the exact normal-

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P. E. KRYSTOW is a corrosion engineer for Esso Research and Engineering Company, Linden, New Jersey. Prior to joining Esso, he was employed as a corrosion investigator for Colgate-Palmolive Company and as an instructor of chemistry at Alliance College. Mr. Krystow received a BS in chemical engineering from Pennsylvania State College (1946) and a Master of Metallurgical Engineering from the Polytechnic Institute of Brooklyn (1952.) He is a member of Sigma Xi and has been a member of NACE since 1949.

M. BALICKI is a professor in charge of the Metallurgical Engineering Division at the Polytechnic Institute of Brooklyn. A native of Poland, he received his metallurgical training at Cracow School of Mines (Dipl. Met. Ing. '33 and Dr. Techn. Sc. '39). Since graduating from that institution he has held teaching and research positions at his alma mater (1932-39); Swansea University College (1940-42); Imperial Chemical Industries, Metals Division, Birmingham, England (1942-44); Polish University College, London (1944-47); and Polytechnic Institute of Brooklyn (1947 to date.) At Cracow Dr. Balicki cooperated with a team engaged in studies of kinetics of oxidation of molten and solid metals. In his present capacity he has supervised work done on the investigation of corrosion of metals and alloys by molten metal.

Abstract

The austenitic stainless steels when exposed to a range of boiling 2 Normal sulfuric-nitric acid solutions pass through a passive zone of negligible corrosion, a transition zone of irregular corrosion and two active zones of substantial corrosion. The corrosion rates in the passive and active zones were as anticipated while the rates in the transition zone were entirely unexpected. A plot of the corrosion rates in the transition zone revealed an unusual hump in the curve whose maximum occurred at a critical concentration.

From spectrographic analyses the corrosion rates or iron, chromium and nickel also were determined. A plot of these rates indicated that the hump in the transition zone of the corrosion curve was attributed to excessive corrosion of chromium in this zone. The percentage of the total corrosion attributable to iron was extremely high and above 99 percent in all the mixed acid solutions. In the transition zone there was an increase of chromium and nickel corrosion with a corresponding decrease of iron corrosion. **6.2.5**

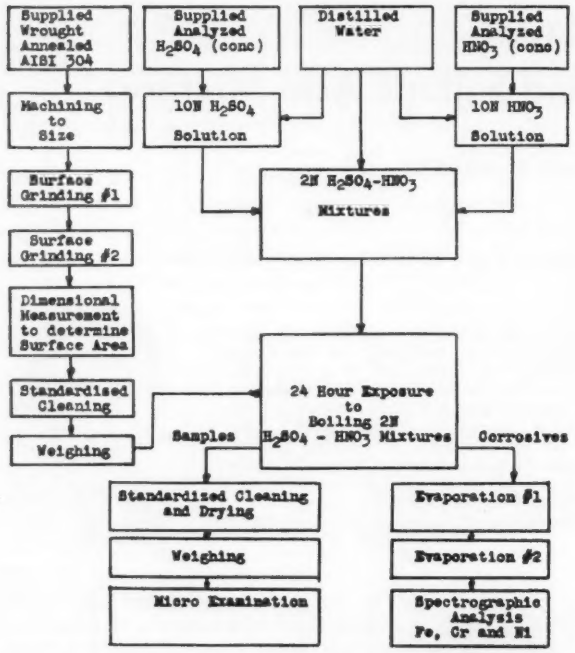

Figure 1—Diagram of procedure used for conducting corrosion tests.

TABLE 1—Composition of AISI 304 Stainless Steel Used in Tests

Element	Percent Composition	Element	Percent Composition	Element	Percent Composition
Fe	70.64	Mn	0.56	S	0.013
Cr	18.26	Si	0.50	C	0.043
Ni	9.96	P	0.022	..	....

ity of which was determined by titration. Further dilution and mixing of these standards was used to prepare eighteen 2 Normal mixtures, varying in proportions of nitric and sulfuric acids. Mixtures 1 and 18 corresponded to 2 Normal nitric and 2 Normal sulfuric acids, respectively. Concentrations of the other mixtures can be seen in column "b," Table 2.

The series of acid solutions used in this work may appear to be simple and adequately described. Closer investigation shows them, however, to be full of uncertainties regarding their chemical make-up and consequently, their properties.[5,6,7] The actual acidity of the series, for instance, in spite of the fact that all the solutions were meticulously adjusted to a 2 normal level, diminishes from the nitric to the sulfuric end of the series. This is primarily a result of the fact that a difference in molarity exists between the two acids; nitric acid furnishes readily one hydrogen ion per HNO_3 molecule, while H_2SO_4 can by dissociation supply two hydrogen ions only one of which is immediately available for reaction. In addition, the extent to which each acid dissociates in the solvent water depends to some extent on its concentration which changes in the series. These factors and many others make accurate predictions of the change in effective acidity of the mixtures, from those of the individual acids, difficult if not altogether impossible.

Because oxidizing power is a property of the mixtures which is of special interest in this work, extensive inquiries were made concerning the magnitude of the oxidizing power of these solutions and the manner in which the oxidizing power of the series diminishes with an increase in the amount of sulfuric acid. Surprisingly enough, the search revealed no quantitative data pertaining to the magnitude of oxidizing power of the acids and to its change in the series of acids used.

The oxidizing power and its opposite, the reducing power, reflect primarily the net properties of the anion species present. The actual acidity and the products of the acid attack on the steel also affect the magnitude of the oxidizing power to some degree. Of the three anions predominantly present in the mixed acid solutions (NO_3^-, HSO_4^- and SO_4^{--}) the nitrate ion (NO_3^-) is a powerful oxidizer while the bisulfate (HSO_4^-) and sulfate (SO_4^{--}) ions, the latter appearing in smaller concentrations, can be considered as relatively neutral or reducing. The oxidizing power of the mixtures is further complicated by the variation of the oxidizing power with temperature and the possibility of complexing between the anions and the numerous products formed by the acid attack of the steel. Complexing in any of the mixed acid solutions would cause a deviation in the linear relationship that is expected to exist between the boiling point and the various acid solutions. Actual findings shown in Figure 2 indicate that complexing of ions apparently did not occur in fresh acids inasmuch as the boiling points followed the linear relationship. This result substantiates the work of Berl and Samtleben.[8]

Testing

As already indicated in Figure 1, exposure of the steel discs to boiling corrosive mixtures was carried out for exactly 24 hours. Large mouthed 1000 ml Ehrlenmeyer flasks, equipped with 30-inch reflux condensers were used to contain exactly 500 ml of the mixed acid. The specimens were positioned at the bottom of the flasks in the manner shown in Figure 3 by means of simple glass fixtures. This method of positioning ensured a vigorous sweeping of the entire surface area by the evenly boiling solution, and eliminated stagnant acid and vapor pockets. Exposures at the boiling point of acid mixtures was employed to eliminate dissolved gases.

In addition to the determination of the overall corrosion rate (loss of weight after 24 hours exposure), a measure of dissolution of chromium, nickel and iron plus impurities (by difference) also was obtained. For that purpose, known quantities of spent corrosive solution containing between 0.001-0.003 grams of corrosion products were concentrated by evaporation. After a quantitative transfer of the concentrate into the craters of carbon electrodes, the evaporation was completed under an infra-red lamp. Spectrographic analysis,[9] which employed an ARL 1.5 meter spectrograph and carbon electrodes free of the elements concerned, ultimately yielded data on the iron, chromium and nickel content accumulated

in the corrosives after the 24 hour exposure. Within experimental error, the respective quantities thus found represent the amount of each element lost by the sample.

In each run, the sample as well as the corrosive media were used only once. Duplicate samples were tested occasionally. To ensure a more positive mapping of the corrosion curves, it was found preferable to use several intermediate acid mixtures rather than to test a number of samples in only a few solutions. This deviates from standard practice but yields data covering the range more fully without materially expanding the volume of the experimental work.

Test Results

The data gathered in this investigation are listed in Table 2. Figures 4, 5 and 6 show a graphical correlation of some of these data. Column "c" in Table 2 contains values of total surface area "A" of the samples tested, indicating the precision with which the samples were prepared. Column "d" shows the loss of weight "ΔW" of samples on 24 hour exposures to boiling nitric-sulfuric acid mixtures. By choosing a surface area of one square decimeter and employing standard calculations, the corrosion rates in mg/dm²/day (MDD) for the samples were obtained and tabulated in column "i" of the table.

The data in column "i" and their graphical representation in Figure 4 are of direct interest to corrosion engineers. In any practical use of these data, the enlargement of the original surface by acid attack with the attendant formation of pits can be neglected. For more fundamental studies of various aspects of corrosion, however, the correlation of the weight loss to the actual, much larger surface should be used. This would provide "true corrosion rate" data which would be much easier to explain and correlate. Arriving at such rates is, unfortunately, beyond the realm of present day technique. A conception of "true corrosion rate" can be implied from the count of the number of pits on the corroded surface of the metal. The measurement of the number of pits on the steel specimens tested was possible up to 0.5 Normal HNO_3-1.5 Normal H_2SO_4 acid mixture. In solutions with a higher sulfuric acid content the pits ran together making the count uncertain. The counting was made at a magnification of 100, employing a 7.5 mm square grated filar eyepiece. Each count was made at three separate locations on the specimens over a fixed surface area. Column "h" of Table 2 and a curve in Figure 6 show the results thus obtained.

Neglecting the trace impurities in the steel tested, it can be assumed that the surface of the samples which reacted upon exposure to the acid mixtures, was composed of iron, chromium and nickel atoms present in weight ratios 70.6: 18.3: 10. The chromium to nickel weight ratio was, of course, 1.83 based on the data shown in Table 1. Each of the above metal atoms can react with the NO_3^-, HSO_4^- and SO_4^{--} anions to form the corresponding salts which are either soluble or insoluble. Any insoluble salts if formed would either fall off or remain on the metal surface as a scale. Since the surface of all the specimens after testing was clean and since the spent corrosives did not reveal any solid scale, it can be safely

TABLE 2—Experimental and Derived Data Showing the Behavior of AISI 304 Steel Exposed 24 Hours to 2 Normal Nitric and Sulfuric Acid Mixtures

a	b				c	d	e	f	g	h		i	j
Code No.	Composition		Corrosive Liquid Weight Percent		Surface Area in Square Inch	W Total Weight Loss in Grams	Chromium Dissolved in Grams	Nickel Dissolved in Grams	Iron Dissolved (by Difference) in Grams§	Number of Pits per 16 Square MM		Total Corrosion Rate in MDD†	Ratio Cr/Ni Corroded (Average)
	HNO_3	H_2SO_4	HNO_3	H_2SO_4						Reading	Average		
1	2.00N	0.00N	11.8	0.0	6.65	0.0018	0.000010	0.000011	0.00178	9,12,10	10	4.12	0.91
1A	2.00N	0.00N	11.8	0.0	6.67	0.0019	0.000005	0.000006	0.00189	.....	..	4.28	0.83
2	1.83N	0.17N	10.8	0.8	6.44	0.0018	.....	.....	.....	.....	..	4.13	...
3	1.67N	0.33N	10.0	1.6	6.65	0.0022	.....	.....	.....	.....	..	5.00	...
4	1.50N	0.50N	9.0	2.4	6.65	0.0028	0.000005	0.000002	0.00279	26,24,37	29	6.39	2.48
4A	1.50N	0.50N	9.0	2.4	6.65	0.0020	.....	.....	.....	.....	..	4.58	...
4B	1.50N	0.50N	9.0	2.4	6.65	0.0028	.....	.....	.....	.....	..	6.36	...
5	1.37N	0.63N	8.3	3.0	6.65	0.0037	0.000004	0.000001	0.00369	42,46,47	45	8.40	3.90
6	1.25N	0.75N	7.6	3.6	6.65	0.0049	0.000012	0.000003	0.00489	41,44,44	43	11.10	4.00
6A	1.25N	0.75N	7.6	3.6	6.65	0.0048	.....	.....	.....	.....	..	11.00	...
7	1.18N	0.82N	7.2	3.9	6.64	0.0046	.....	.....	.....	45,36,39	40	10.60	...
8	1.13N	0.87N	6.9	4.2	6.67	0.0051	0.000018	0.000004	0.00508	58,38,46	47	11.40	4.45
9	1.00N	1.00N	6.1	4.8	6.64	0.0040	0.000007	0.000002	0.00399	46,42,55	47	9.05	3.50
9A*	1.00N	1.00N	6.1	4.8	6.61	0.0034	0.000003	0.000001	0.00399	.....	..	8.05	3.15
9B	1.00N	1.00N	6.1	4.8	6.64	0.0035	.....	.....	.....	.....	..	8.10	...
10	0.93N	1.07N	5.7	5.1	6.65	0.0047	0.000011	0.000002	0.00469	47,33,41	41	10.70	5.4
11	0.83N	1.17N	5.1	5.5	6.65	0.0082	0.000011	0.000003	0.00819	40,41,43	41	18.60	3.7
11A	0.83N	1.17N	5.1	5.5	6.65	0.0084	.....	.....	.....	.....	..	19.00	...
12	0.75N	1.25N	4.6	5.9	6.67	0.0168	0.000012	0.000004	0.01678	45,44,50	46	37.80	3.0
12A	0.75N	1.25N	4.6	5.9	6.65	0.0135	.....	.....	.....	.....	..	30.90	...
13	0.67N	1.33N	4.1	6.3	6.65	0.0212	.....	.....	.....	.....	..	47.60	...
14	0.50N	1.50N	3.1	7.0	6.68	0.0546	0.000068	0.000169	0.05436	51,48,52	50	122.60	0.4
14A	0.50N	1.50N	3.1	7.0	6.64	0.0490	.....	.....	.....	.....	..	110.00	...
15	0.33N	1.67N	2.1	7.8	6.65	0.1861	.....	.....	.....	.....	..	425.00	...
16	0.25N	1.75N	1.6	8.1	6.67	0.4240	0.000530	0.000890	0.42258	‡	..	955.00	0.6
17	0.17N	1.83N	1.1	8.5	6.65	1.0411	.....	.....	.....	.....	..	2365.00	...
18	0.00N	2.00N	0.0	9.2	6.65	3.8505	0.010400	0.015800	3.82430	‡	..	8700.00	0.65
18A	0.00N	2.00N	0.0	9.2	6.65	3.8624	.....	.....	.....	.....	..	8730.00	...

* Specimen heat treated to remove cold working stresses developed by machining and surfacing.

† Milligrams per square decimeter per day.

‡ Many pits which tended to run one into another.

§ Iron plus impurities obtained by difference from spectrographic analysis of Cr + Ni ions. These spectrographic analysis were determined at an accuracy between 30 to 50 percent from absolute values.

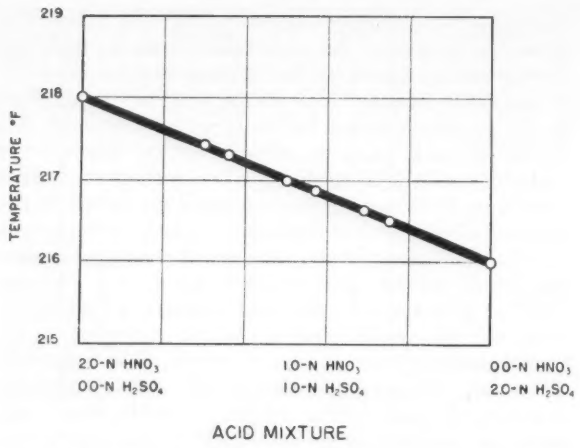

Figure 2—Boiling points of some of the 2 Normal nitric and sulfuric acid mixtures.

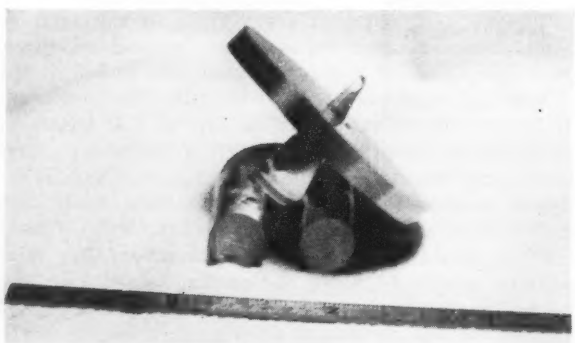

Figure 3—Glass fixture for positioning of test disks on the bottom of Erlenmeyer flasks.

concluded that all the metal atoms corroding from the surface of the test specimens formed soluble salts with the anions present. The amount of chromium and nickel dissolved in the mixed acid solutions was determined by means of spectrographic analysis and was readily converted into grams of chromium and nickel lost from the metal surfaces after 24 hour exposure. Such data are listed in columns "e" and "f". The data shown in column "g" list the grams of iron lost and were obtained by taking the difference between the total corrosion weight lost (column "d") and the sum of Cr and Ni lost (columns "e" and "f"). To make these data independent of the small variations in the original sample surface areas, the 24 hour weight losses of Cr, Ni and Fe from one square decimeter of surface area were calculated. Figure 5, illustrates how these rates vary with the acid mixtures used. The absence of parallelism between the individual corrosion rate curves for Cr, Ni and Fe indicates that these elements, although present in the steel in a fixed ratio, do not corrode in the same proportion from the metal surface. To show this more clearly the ratio of greatest interest (Cr/Ni ratio) has been calculated and assembled in column "j". This ratio has been represented graphically in Figure 6.

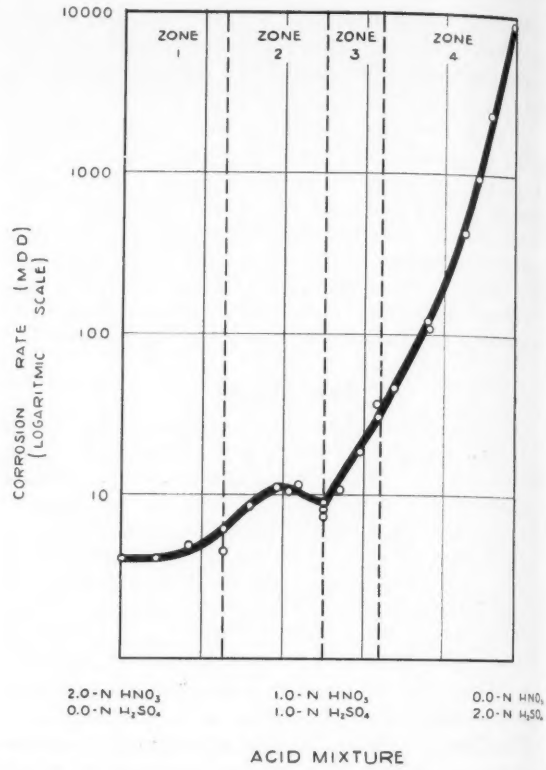

Figure 4—Over-all corrosion rate of AISI 304 stainless steel after 24 hour exposure to mixed acid solutions.

Survey of Results

The survey of the findings can best be made with the aid of Figures 4, 5 and 6. These plots reveal some though not an excessive scatter of the experimental points. They indicate that by means of various precautions, the effect of incidental variables could be kept under control and that it was possible to establish the change in the corrosion rates as a function of the acid mixtures.

As expected, the over-all corrosion in 2 normal acid solutions high in HNO_3 is very small, less than 10 MDD. In 2 Normal solutions high in H_2SO_4, however, total corrosion is very large, well over 1,000 MDD. For this reason, corrosion rate data were plotted using a logarithmic scale. The curves of the over-all corrosion rate (Figure 4) and individual corrosion rates for Cr, Ni and Fe (Figure 5) between the terminal corrosive mixtures are not fully simplified by condensing the corrosion rate scale from Cartesian to logarithmic coordinates, inasmuch as these plots are curvilinear. A further condensation of the ordinate was obtained by employing a log-log scale for corrosion rate (Figure 6) which resulted in the "straightening" of the curvilinear portions and an exaggeration of the "hump" in the range 1.5 normal-1.0 Normal HNO_3 mixture.

Zones of Corrosion Behavior

An analytical survey of the plots shown in (Figures

4, 5 and 6) reveals that four distinct zones are formed, each with its characteristic corrosion behavior.

The first or "passive" zone covers the acid mixtures from 2 Normal HNO_3 to the point where the hump commences (i.e., to about 1.5 Normal HNO_3). In this range, the over-all and the individual corrosion rates of Fe, Cr and Ni are almost negligible. The ratio of Cr to Ni atoms dissolved is apparently below the original 1.83 ratio. Visual observation of the samples revealed that the number of pits rises sharply and that the pits are small, shallow and far apart.

The second zone which may be called the "transition" zone is well characterized by the appearance of a "hump" and covers the range 1.5 Normal to 1.0 Normal HNO_3 acid in the mixtures. In this zone, the over-all corrosion rate as well as the corrosion rates of Fe, Cr and Ni increase to a maximum and then decrease to a level not quite as low as the starting level. The number of pits in this region remains relatively constant. The pits appear to be somewhat larger and deeper with a decrease in HNO_3 content. The Cr/Ni ratio becomes greater than the original 1.83 ratio and also shows a maximum at approximately the same acid concentration where maximum corrosion occurred in the transition zone.

The third or "semi-active" zone which extends from 1.0 Normal to 0.73 Normal HNO_3 acid mixtures is not too well revealed by the log plot (Figures 4 and 5) of the corrosion curves. Use of a log-log scale indicates that corrosion in this zone increases exponentially at about twice the rate of that shown in the same curve for the fourth zone. The upper limit of this zone seems to coincide with the point at which the Cr/Ni ratio descends to the 1.83 ratio. Pits in this zone are numerous, deep and closely packed.

The fourth, or "active" zone covers the remaining acid mixtures. The total and individual corrosion rates are several hundred times higher than in the first zone. The increase in over-all corrosion rate is exponential as shown by the straightening of the log-log plot. The Cr/Ni ratio in the zone decreases well below the ratio present in the steel, indicating that significantly more nickel is corroding than chromium. The pits run together and become very deep.

Discussion of Results

The corrosion behavior of stainless steel in 2 Normal nitric acid is not fully known. The surface of the steel prior to immersion is composed of Fe, Cr and Ni ions present in overall proportions of 70.6 Fe, 18.3 Cr, and 10 Ni. This ratio will vary from one spot on the metal surface to another. The metal ions, even on the surface of newly polished specimens, will be chemically or physically combined with oxygen. Consequently, the composition and structure of the oxide and/or adsorbed oxygen film also is expected to vary from spot to spot. Owing to these spot to spot differences in the composition, structure and thickness of films and also to the differences in specific reaction rates of the various films with nitric acid, the acid contact with bare metal is likely to be established initially at certain "key" spots.

These "key" spots which first expose bare metal

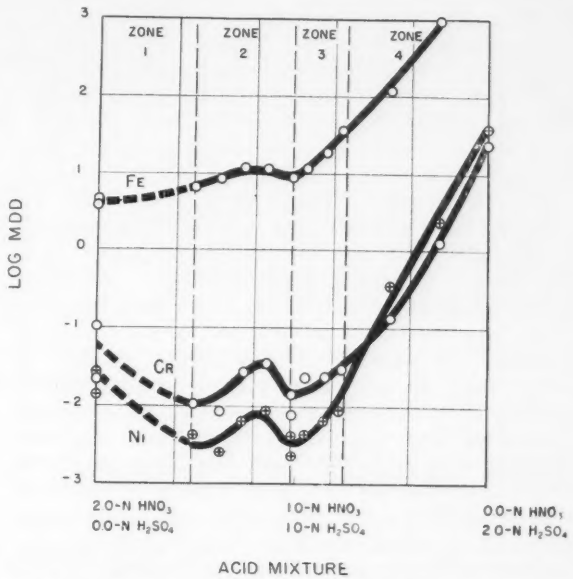

Figure 5—Individual corrosion rates (MDD) of Cr, Ni and Fe corroding from AISI 304 stainless steel after 24 hour exposure to boiling mixed acid solutions.

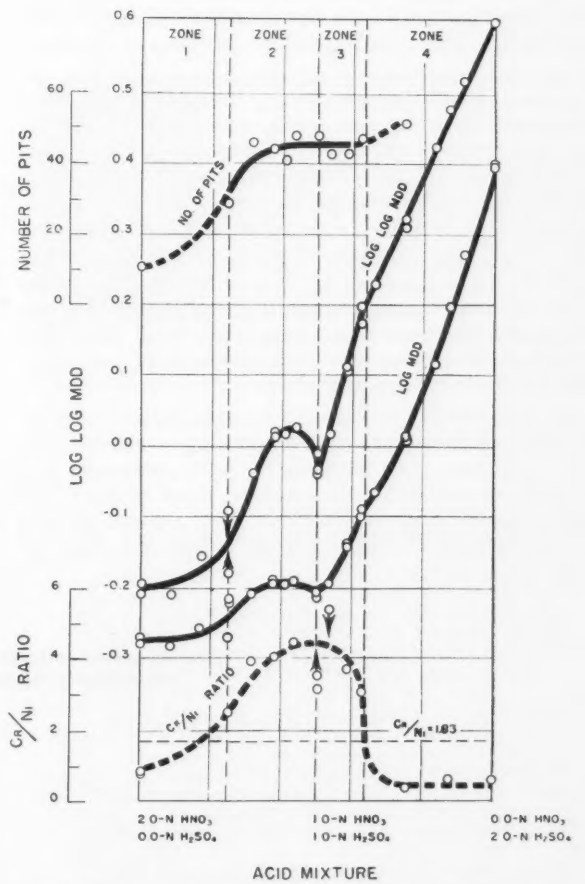

Figure 6—Overall corrosion rate (MDD) of AISI 304 stainless steel, number of pits and Cr/Ni ratio. Results pertain to 24 hour exposure to the boiling point of the mixed acid solution.

are chemically more active than the passive oxygenated surfaces immediately surrounding them and as a result they are believed to suffer preferential galvanic corrosion which leads to pitting. In the case of a solution containing all nitric acid, the "key" spots are few and wide apart. Apparently the chromium atoms in the steel are not completely immune to attack as evidenced by the presence of some chromium in the spent 2 Normal HNO_3. Iron, as expected, was the principal metallic constituent in the spent solution. Over 99 percent of the metallic constituents in the spent solution was iron in all four zones.

The introduction of sulfuric acid to the nitric acid increases the number of "key" spots as may be judged from the number of pits found after the exposures. Dilute sulfuric acid apparently is successful in reducing more spots on the oxygenated film, thus exposing more bare metal and increasing the corrosion rate accordingly. Eventually, as more and more sulfuric acid is present (semi-active and active zones) more and more bare metal is exposed until a point is reached where the pits tend to run together and the surface occupied by the oxygenated film becomes very small. Once this film is completely destroyed somewhere between the semi-active and active zones, the corrosion rate assumes a new exponential rate of increase as indicated in Figure 4. The break-point between the semi-active and active zones appears to be related to the point where the ratio of Cr/Ni corrosion falls below the original Cr/Ni ratio of the steel.

At the "transition zone" the number of pits remains approximately constant. Therefore, it can be presumed that the area occupied by the bare spots as compared to the area of oxygenated film is approximately constant. Under these conditions a constant corrosion rate would be expected instead of the variation of corrosion rate shown by the "hump" in the curve. The variation of the corrosion rate in this zone is as intriguing as it is difficult to explain. Several hypotheses concerning the origin of the "hump" have been considered. They have been subsequently abandoned as inadequate or not fully supported by experimental findings.

It can be noted in Figure 5 that the amount of iron, nickel and chromium corroding change somewhat in the transition zone. Apparently both chromium and nickel are preferentially corroded most probably by the galvanic type of corrosion. The amount of iron corroded in the transition zone is lowered. This redistribution of corrosion of the individual metal atoms is apparently connected with the mechanism responsible for the unusual "hump" in the corrosive curve.

Conclusions

From the data presented in this paper it can be briefly concluded that the stainless steels when exposed to a range of 2 Normal HNO_3-H_2SO_4 acid solutions which vary in their ability to cause corrosion from slight to severe, pass through a passive zone of negligible corrosion, a transition zone of irregular corrosion and two active zones of substantial corrosion.

The use of spectrographic equipment in determining the corrosion rates of individual metals in alloys is a valuable tool for extending present knowledge of the corrosion of metals. It is urged that other investigators consider the use of this instrument for their corrosion studies. The spectrographic technique described in the procedure was not the most accurate type possible for determining the corrosion rates of the individual metals. A still greater accuracy can be obtained by employing the more detailed and comprehensive spectrographic methods.[9]

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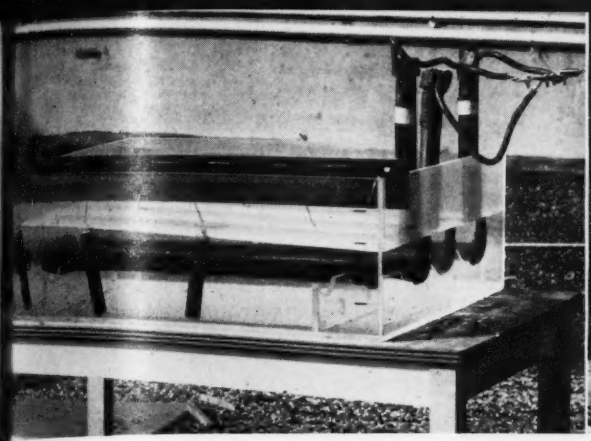

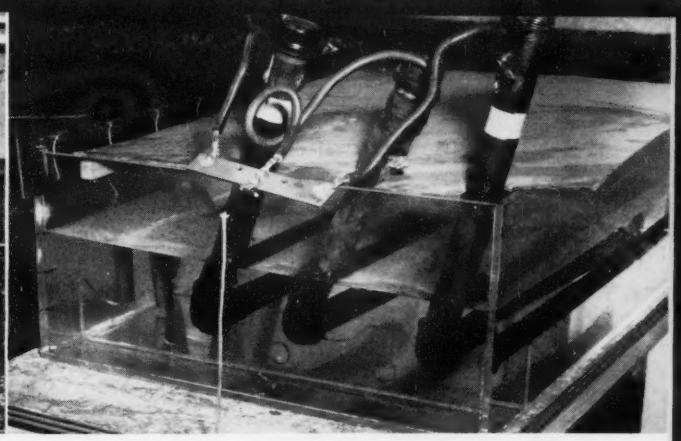

Figure 1—(Left) Test box loaded with three tape samples. Note notched supports to keep samples separated and carbon anodes in foreground.
Figure 2—(Right) Negative bus for tape test. Note box lid to keep pipe separated.

Testing Wrappings on Cathodically Protected Submerged Pipe and Fittings*

By H. M. CLAYTON

THE LIGHT, GAS & Water Division of Memphis, Tennessee has adopted the policy of installing only coated and wrapped gas mains and services. Because steel pipe with welded joints is used, one of the problems incidental to this work is covering the welded or fitted joints in the service pipes after installation. Uniformity of coating would require the use of hot enamel on all welded joints. Because application of this hot enamel has disadvantages when applied in the field, many cold coating materials and tapes have been brought out to cover the joints without the need of heating the coating, with its attendant disagreeable odor and hazards.

In fact, there appeared such a multiplicity of tapes and cold coatings all of which reported to be perfect, that it was decided to make some simple tests to determine, if possible, which tapes or coatings should be used.

One of the most important reasons for a coating, when cathodic protection is to be applied, is limiting current flow between the soil and the pipe. Consequently, it was decided to run a test designed to show the resistance of the tape covering to the flow of current or, as finally determined, to show the current flow resulting from a given voltage.

Effect of Aging Considered

Another factor to be considered was the effect of aging. It was decided that an effective test of this nature, without actually exposing the material for an extended period, might be accomplished through regular increases in voltage each week for several

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HENRY M. CLAYTON is a member of AIEE, NACE and NAPE and a registered engineer of the state of Tennessee. He organized and has directed the Corrosion Prevention Department of the Memphis Light, Gas and Water Division since 1950. A student of electrical engineering at Texas A & M, he served in the infantry in World War I. He was employed successively in various engineering capacities by Texas Power and Light Company, Little Rock Railway Electric Company, Little Rock, Ark.; Arkansas Central Power Company, Memphis Power and Light Company, Memphis, Tenn. Since 1939 he has been standardization engineer for the Memphis Light, Gas and Water Division.

Abstract

All 20-mil tapes failed when tested by the Light, Gas & Water Div. of Memphis, Tenn. in 2000 ohms/cm³ water wrapped over 1-inch pipe carrying impressed voltages of —.85 to —2.5. Ten-mil tapes performed better. The principal reasons for failure were poor adhesives and tape elasticity and memory which tended to pull away wrappings over elbows and caps. Coal tar enamel tested under the same conditions performed well.

Test equipment included a device for measuring the conductivity of the water and a transparent plastic box in which the tested samples were submerged. Close check was kept on applied potentials. A record was kept of water absorbed by the wrappings. It is believed increased current flow was caused by water creeping under tapes rather than absorption.

Tests were run for periods of eight weeks, gradually increased voltages having the effect of accelerating the tests. Data are graphed for typical tests and a table of data on a typical sample is given. 5.4.5

weeks. Voltages finally adopted were a minimum of .85 volts to a Cu-$CuSo_4$ electrode in the enclosing medium and a maximum of 2.5 volts.

It was decided further to place these coatings on 1 inch pipe and suspend them in water so observations during the test could be made and samples moved about so current and voltage conditions could be equalized for all samples.

Because local soil resistivity averages about 2000 ohms/cm³, it was decided to use water having a similar resistivity and with a pH of 7, at the start of each test.

It was also believed desirable to learn how much water would be absorbed by the coating, so a pair of balance scales was obtained to make measurements.

A test box made of ⅜ inch transparent plastic was used. It was designed to hold three test samples and was 30 inches long by 22 inches wide and 10 inches high. When a test was underway, 15 gallons of tap water were used with 4.5 grams of salt added to bring resistivity down to 2000 ohms/cm³. Carbon anodes (taken from No. 6 dry cells) were used. Notches in two supports inside the tank held the three samples in place. A lid of composition board was used to keep out foreign matter and hold the samples erect.

Device for Testing Water

It was necessary also to design a tube for testing water resistivity as it changed between tests. The test aimed at correcting all readings to 2000 ohms/cm³ for uniformity of results. A simple tester was made from 1¼ inch inside diameter transparent plastic tubing 12 inches long and stoppered at both ends with corks. Copper disks the size of the small end of each cork were used as current electrodes. One disk was held to the cork by a solid No. 6 wire soldered to the disk and passed through the cork. The other disk had a hole drilled through the center and was soldered to a piece of ¼ inch copper tubing driven through the cork. The purpose of the tubing was to let out air and excess water so the plastic tube could be filled completely with the water sample. Two holes then were drilled separated by a distance numerically equal to the cross section area inside of the tube expressed in square centimeters. The tube was then heated near each drilled hole and a piece of copper wire of slightly larger size than the hole was forced through each hole. When the tube cooled, the wires were imbedded firmly. These two wires served as voltage terminals and permitted testing water resistivity in the same manner as soil is in a soil test box.

A high resistance DC millivolt meter, a DC milliammeter, together with a copper-copper sulfate electrode completed the equipment needed to carry out the tests.

The following scales were required on the meters: The high resistance (200,000 ohms per volt) DC millivoltmeter requires a scale of 0-1 volt and 0-5 volts. The DC milliammeter has a scale of 0-.1 ma and 0-10 ma.

Two 1½-volt dry cells were necessary for measuring water resistivity.

A balance type scale of sufficient accuracy to read to the nearest one-tenth gram and large enough to handle weights up to 20 kilograms was used because the pipe, with test sample in place, weighed approximately 3 kilograms.

The direct current necessary was obtained from a rectifier made up of a transformer and selenium rectifier with a 100-watt rheostat connected in the DC circuit so that accurate adjustment of the applied voltage could be made.

Standard Pipe Combination Used

The samples to be tested were wrapped on a standard combination of pipes and fittings arranged in the form of an ell. In order that comparative figures could be obtained it was very important that all assemblies have similar fittings and submerged dimensions. Two pieces of 1 inch pipe which were threaded at both ends were used. The pipe to be submerged was 27 inches long; the other piece was 14 inches long and stood upright. A copper conductor was welded to the upright piece. These two pieces of pipe were connected by an ell, the remaining ends being capped with 1 inch caps. This provided not only straight pipe but also a pipe cap and an ell around which the material under test was wrapped. A strip of sheet copper served as a negative bus to which was connected each of the three samples. It was so arranged that the connection between the samples and the bus could be removed for weekly tests without breaking the circuit.

In preparing samples for test either the manufacturer or the manufacturer's representative was invited to apply the tape or coating, so that each received equal opportunity to make a good showing.

Because weight of water absorption was a factor to be determined, the first test consisted of dipping the sample into the water, removing it and permitting the free water to drain off, then weighing the sample and pipe. This was done to learn how much water would cling to the outside of the tape at the end of the test so that net water absorption could be obtained.

Samples then were placed in the water and connected to the negative bus. Samples were marked by notches filed into the pipe so they would be easy to identify.

How Tests Were Conducted

The location of each sample in the test rack was recorded also, because each week the position of all samples was changed so that proximity of the anode would average out for all three samples throughout the test. Resistivity of the water was then re-checked and recorded so that current flow indicated could be corrected to a 2000 ohms/cm³ basis. The rectifier was then turned on and the rheostat adjusted so that the voltage between the negative bus and copper-copper sulfate electrode in the water was .85 volt. The applied voltage between the positive anodes and the negative bus also was read and recorded.

After this, each sample was individually and separately disconnected and the current flow, if any, read

and recorded. Care was taken to be sure that the circuit was never broken between the negative bus and the sample (i.e., the milliammeter was shunted around the connection between the sample and the negative bus before this connection was broken). The same care was used when moving sample from one position to another, when flexible shunt leads were clipped across the connection between the sample and the negative bus to maintain that connection while moving the sample.

Weekly, after the first set of voltage and current readings were taken, two sets of readings were taken for eight weeks. One set of readings with DC voltage as found and one set of readings after adjustment of the DC voltage to the next step were made. Resistivity of the water also was checked weekly.

Beginning in October, 1952, tests have been made on various tapes and pipe coverings under the supervision of T. W. Paris, Corrosion Design Engineer and B. L. Osborne, Corrosion Test Engineer. Since that time, 11 tests of three samples each have been completed. In other words, 33 samples of coverings have been tested and the findings recorded.

Typical Record of Tests

Table 1 is a typical record of tests made on one sample. It will be noted that, at the end of the period, with a copper-copper sulfate reading of 1.93 volts, .0075 milliamperes were flowing into the sample. Note that there were readings made of the applied direct current voltage, flow of current to the sample from the water, the resistivity of the water in ohms/cm³ and the voltage to copper-copper sulfate from the pipe, as well as the weight in kilograms at the beginning and end of the test. Notation also was made as to the appearance of the coating at the time of each test.

Figure 3 shows results of a test made with standard coal tar enamel application without paper wrapping. This test was made to establish a norm for future tests.

Evidently initial tests have been accurate because re-tests of the same materials invariably have given

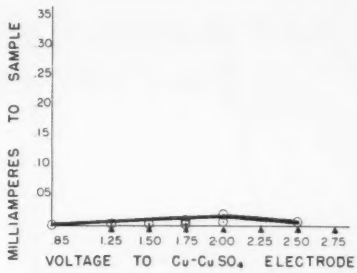

Figure 3—Current flow at different voltages to coal tar enamel coating.

results similar to those of previous tests. This substantiates reliability of the data.

Figure 4 indicates the flow of current through 20-mil tape at various voltages between the pipe and copper-copper sulfate electrode. This sample was not approved for use.

Figure 5 shows a graph of results of a test on a 10-mil tape which also was not approved.

Figure 6 shows the graph of results on a 10-mil tape that was approved for use.

Conclusions

After making the 33 tests of various tapes and coverings the following conclusions are indicated:

1. Of the two principal tape materials tested, it was assumed that dry polyvinyl chloride and polyethylene tapes had a high enough resistance to the flow of current so that the current would be so slight in either tape it would not result in an appreciable difference. After wetting, however, it could not be determined whether water absorption by the tape material or water creeping under the tapes resulted in an increase of current flow. Observation indicates that current flow increased principally because water crept under the tape.

2. The effectiveness of the adhesive used was probably one of the major factors in determining the current limiting ability of the tape. Without an effective adhesive, the tape could creep and allow the passage of water and current between the overlapped layers.

TABLE 1

SAMPLE No. 2

Type of Covering 10 mil tape **Weight Before Test 3.0210 K.G. Wet**
Starting Time and Date 8:40 am 7-10-53 **Percent of Lap 50%**

Date 1953	Time a.m.	Applied D.C. Voltage 1	Applied D.C. Voltage 2	Milliamps to Sample 1	Milliamps to Sample 2	Position of Sample 1	Position of Sample 2	Rho Ohms/cm³ of Water	Volts to Cu-CuSO₄ in Water 1	Volts to Cu-CuSO₄ in Water 2	Weight in k.g.s.	Condition of Covering
7-10	8:50	....	1.08	.....	.0005	..	B	2130	....	.85	3.0210	Good
7-17	8:40	1.07	1.25	.0000	.0005	B	A	2000	.69	.85	.....	Good
7-24	8:40	1.25	1.80	.0005	.0010	A	C	1750	.79	1.25	.....	Good
7-31	9:15	1.80	2.23	.0010	.0020	C	B	1330	1.14	1.50	.....	Good
8- 7	8:45	2.25	2.32	.0020	.0025	B	A	1540	1.43	1.50	.....	Slipping
8-14	9:00	2.32	2.71	.0030	.0043	A	C	1630	1.53	1.75	.....	Slipping
8-21	8:40	2.73	2.73	.0050	.0055	C	B	1750	1.75	1.75	.....	Slipping
8-28	8:45	2.68	3.13	.0050	.0095	B	A	2000	1.68	2.00	.....	Loose at end
9- 3	8:45	3.12	3.35	.0100	.0095	A	C	2000	1.90	2.00	.....	Loose at end
9-10	8:45	3.33	3.70	.0090	.0130	C	B	1750	1.95	2.50	.....	Loose at end
9-17	8:45	3.72	....	.0075	.....	B	..	2120	1.93	....	3.0238	Loose at end
....	....	....	....	.....	.....	..	..	....	....	....	2.8 grams	Water absorption

Do not under any circumstances break continuous flow of d.c. Current.
1 As found.
2 As left.

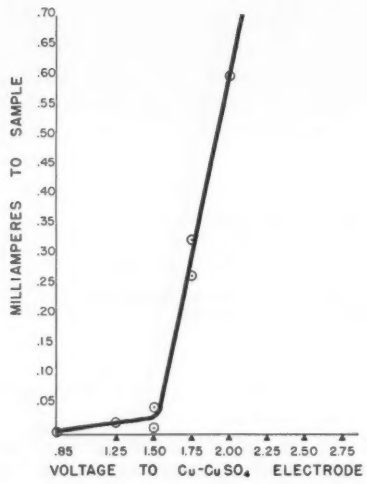

Figure 4—Results of test with 20-mil tape. This is typical of all 20-mil tapes tested.

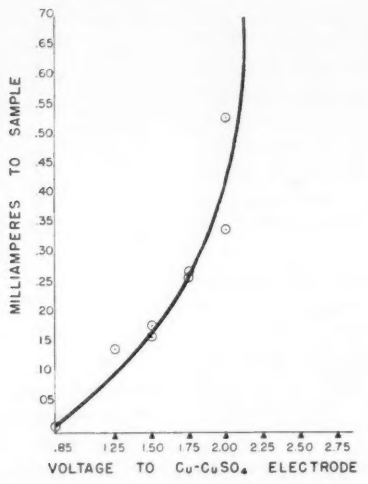

Figure 5—Current flow at various voltages for a 10-mil tape that was not approved.

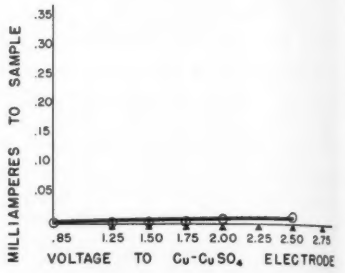

Figure 6—Current at various voltages for a 10-mil tape that was approved.

3. Even a good adhesive, however, cannot compete with the pull of a very elastic tape at the end of the windings unless very great care be used in applying it without stretch. Even though the last few turns are placed without tension, the tape's natural elasticity will cause it to creep until movement takes place on the end wrap. When such a tape was used for short wrappings and over fittings as in the test described, this slippage was found to be serious.

4. Another factor that was found to be very important was the memory of the tape, that is, the tape's desire to return to its original flat and straight condition. The poorer the memory the better the results obtained especially when wound around irregular objects such as pipe fittings. The tapes which gave the best results were tapes with very poor memories. This factor is not believed to be of as much importance, however, when tapes are applied on longer runs of straight pipe only.

5. Poor results were obtained with all 20-mil tapes. The stiffness due to extra thickness evidently resulted in the inability of such a tape to accommodate itself to a 1 inch pipe and fittings.

In conclusion thanks are extended to all tape manufacturers who have been very cooperative. The author would like to point out again that tests were not made on straight pipe. It is possible, therefore, that results obtained on straight pipe would not be the same as those obtained on the tests described in this paper.

Any discussions of this article not published above will appear in the December, 1956 issue.

Attack of Scaling-Resistant Materials by Vanadium Pentoxide And Effect of Various Alloying Elements Thereon*

By E. FITZER* and J. SCHWAB*

Abstract

Investigation into possibilities of developing metallic materials able to stand up under the attack by the combustion gases in crude-oil fired gas turbines is described. Preliminary comparative scaling tests were conducted on metallic copper, nickel, iron, and on chromium steels in pure oxygen, V_2O_5-saturated oxygen, and in oxygen coupled with intermittent immersion into molten V_2O_5. V, Mo, and W were found to be harmful elements. An explanation is given of action of V_2O_5. Other oxides and mixtures of oxides causing accelerated oxidation also are considered.

An account is given of the development of a rapid test which would determine resistance to attack by V_2O_5. Test data are given on numerous steels and alloys known to be scaling resistant. Nature of V_2O_5 attack upon iron-base alloys is compared with that for nickel and Ni alloys. Numerical data are given on effect of Cr, Ni, and Si on scaling by V_2O_5. It is concluded that a metallurgical approach can partly solve the corrosion problem involved in V_2O_5 scaling.

3.5.9

Introduction

THE PROGRESSING development of gas turbines has stimulated interest in adapting this type of power for use in stationary installations and for the propulsion of ships. The economy of these applications depends primarily upon the possibility of burning an unrefined cheap fuel such as crude oil in gas turbines. In practice, however, all attempts to use gas turbines for such purposes have proven unsuccessful because of corrosion problems.

It has been found that all known scaling-resistant materials of construction are incapable of withstanding an attack by the combustion gases in crude-oil fired gas turbines. The attack at temperatures of about 700-800 C (1290-1470 F) already is so intensive that it gives rise to what is generally described as "catastrophic" oxidation. High-alloyed ferritic and austenitic chromium steels scale about as badly as unalloyed iron. There appears to be general agreement that a metallurgical solution of this corrosion problem seems impossible. It also is generally conceded that the cause of this accelerated metal oxidation resides primarily in the vanadium content of crude oil.

Table 1 shows the analyses of an oil, of its combustion residue, and of the crust formed on the first row of turbine blades.[1] The data in the table demonstrate the dominant part played by V_2O_5 in the formation of the crust (33 percent). On the basis of the V_2O_5 content of the ash, the vanadium content of the fuel oil is found to be 0.015 percent.

As yet, no detailed studies have been conducted to establish the minimum vanadium content in petroleum sufficient to cause such destruction. It must, however, be taken into consideration that, in the face of so great a fuel throughput as is encountered in gas turbines, even a very small vanadium content in a crude oil will result in slagging. It is well known that the vanadium content of oil ash fluctuates greatly depending upon the various sources of the crude oil. Other metals, such as nickel, also are found in oil ash, although vanadium accounts for the bulk of the metal content (up to 80 percent V_2O_5 in South American crude oils). Coal ash also contains vanadium.

Vanadium probably exists in crude oil in the form of organic sulfide or alkali-metal compounds. For this reason, Na_2SO_4 also occurs in the combustion residues, and the reported studies involving corrosion tests of scaling-resistant alloys have been conducted with various mixtures of Na_2SO_4 and V_2O_5 as synthetic ashes. These produce similar destructive effects as pure V_2O_5.

It should be emphasized that this accelerated oxidation involves a combined attack by oxygen or air and fuel-oil ash. The attack by pure molten V_2O_5 in the presence of a slight quantity of oxygen is relatively small. Gas turbines, however, are quite generally operated with a large excess of air, the air-gas ratio in the mixture being about 120/1, and the waste gases still containing about 17 percent of free oxygen in addition to CO_2 and water vapor.

Besides vanadium pentoxide, other oxides also exert a similar effect upon the accelerated oxidation of scaling-resistant alloys. Although these other oxides (Bi_2O_3, MoO_3, WO_3, and PbO) are practically absent from crude-oil ash, this observation is important in connection with the accelerated oxidation. This is because similar scaling phenomena can occur if these scaling-accelerating metals are present as alloying elements in the material exposed to scaling and the attack is exercised by ash-free air or by pure oxygen. Among the alloying elements, too, vanadium acts most strongly in accelerating oxidation, followed by molybdenum and tungsten.

Accelerated Oxidation Theories

Three possible explanations for this accelerated oxidation have been discussed in the literature as of this date. These theories are as follows:

1. The above-mentioned oxides act as catalysts to transfer or split off oxygen.
2. The accelerated scaling is brought about by lattice defects resulting from the incorpora-

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* Institute for Inorganic-Chemical Technology, Technische Hochschule, Vienna, Austria.

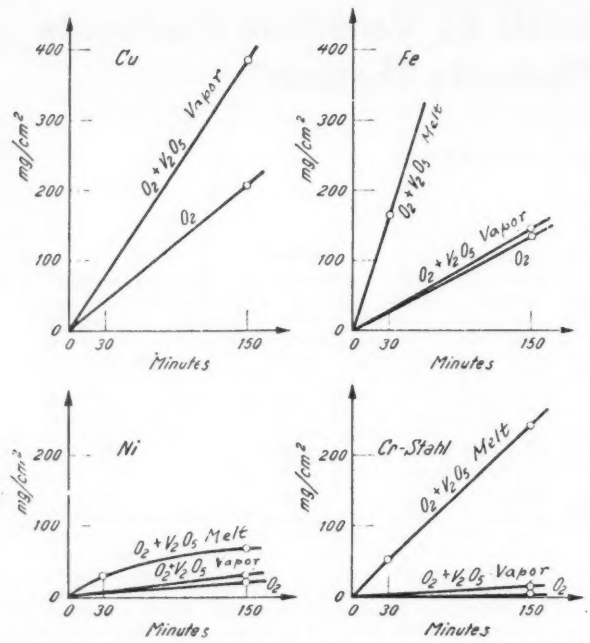

Figure 1—Comparative scaling tests of Cu, Fe, Ni and Cr steel in O_2, $O_2 + V_2O_5$ vapor and $O_2 +$ molten V_2O_5.

TABLE 1—Analyses of Fuel Oil, Its Ash, and Crust Formed on First Row of Blades (E. Franke[1])

Fuel Oil		Ash		Crust	
C	84.99%	Insol	15.0%	Insol	1.0%
H	12.34%	Fe_2O_3	5.5%	Fe_2O_3	4.7%
S	1.52%	NiO	4.7%	Nio	17.0%
Ash	0.044%	V_2O_5	62.0%	V_2O_5	33.0%
		Alkali	3.7%	Alkali	13.5%
Organic V	~0.015%	SO_3	1.85%	SO_3	17.5%
		Remainder	7.25%	Ign. Loss	14.0%

TABLE 2—Melting Points of Oxides and Oxide Mixtures Causing Accelerated Oxidation

OXIDES	Degrees C	Degrees F	Remarks
PbO	888	1630	
Bi_2O_3	820	1510	
MoO_3	795	1465	
V_2O_5	670	1240	
$V_2O_5.\frac{2}{3}Na_2O$	560	1040	
$V_2O_5.Na_2O$	630	1165	
$V_2O_5.1.5Na_2O$	580	1075	
$V_2O_5.3Na_2O$	850	1560	
MoO_3-Cu_2O	535	995	On 92-8 Cu-Al alloys
MoO_3-MoO_2-Cu_2O	470	880	
MoO_3-MoO_2-Cr_2O_3	770	1420	On 25 percent Cr steel
MoO_3-MoO_2-Cr_3O_3	725	1335	On 18-8 Cr-Ni steel

tion of these oxides into the otherwise stable surface layers.

3. The destruction of the materials is attributable to the slagging action of the low-melting oxides.

Catalytic Action

The first explanation, based on catalytic action, is supported primarily by the unusually high dissociation pressure of V_2O_5 above its melting point. It should be pointed out in this connection that V_2O_5 is employed as a technical oxidation catalyst (as, for example, in the production of contact sulfuric acid). Ferrovanadium also is employed as an oxidation catalyst (as, for example, in determining carbon in oxidation-resistant metals by combustion). The decomposition pressures of MoO_3, however, are only about 1/100 those of V_2O_5. On the other hand, such salts as vanadates and molybdates probably have a higher decomposition pressure than the pure oxides.

It also has been observed that the attack by V_2O_5 occurs most often in a quiescent atmosphere, which again lends support to the explanation based on oxygen removal. For example, perfectly scaling-resistant chromium-steel specimens suffer accelerated oxidation while being heated in the same space as a vanadium-containing steel. This indicates that V_2O_5 can exert its effect only through the vapor phase.

Metal Scaling Process

The second explanation is backed primarily by the basic researches of C. Wagner[2] and K. Hauffe[3] on the metal-scaling process. Hauffe[4] quite recently succeeded in providing experimental proof that foreign metal oxides can either accelerate or retard scaling. He also succeeded in interpreting these effects theoretically on the basis of defect-concentration changes in the oxide lattices.

Melting Points

The third explanation of this catastrophic oxidation, in which a slagging of otherwise stable oxide layers by the ash is advanced as the cause of the phenomenon, appears to be supported mainly by the low melting points of the attacking oxides. Some pertinent data are presented in Table 2. Various eutectics of the molybdates have also been investigated, in particular by J. L. Meijering and G. W. Rathenau.[5] The melting points found would satisfactorily explain the occurrence of this accelerated oxidation in the observed temperature range; i.e., above about 700 C (1290 F).

Experiments undertaken by the authors to clarify the causes of corrosion have shown that the strong destruction of materials must be overwhelmingly attributed to slagging. For this purpose, comparative scaling tests were carried out with copper, nickel, iron and chromium steel in pure oxygen, in V_2O_5-saturated oxygen and in oxygen, interrupted by repeated intermediate immersion in molten V_2O_5.

It can be seen from Figure 1 that pure iron is not affected by V_2O_5 vapor in its oxygen-scaling behavior and that V_2O_5 vapor accelerates the oxygen scaling of nickel and copper only slightly. It is clear also that chromium steel, which is resistant to pure oxygen, experiences a tenfold attack in the presence of V_2O_5 vapor. Furthermore, a brief immersion in molten V_2O_5 already decisively affects the attack on chromium steel, whereas the scaling of pure nickel is not substantially affected by immersion in molten V_2O_5. The attack upon iron also is multiplied by this treatment. No usable values could be obtained for the easily-scaling copper.

If the V_2O_5 vapor exerted an exclusively catalytic action upon the oxidation, the resulting effect would

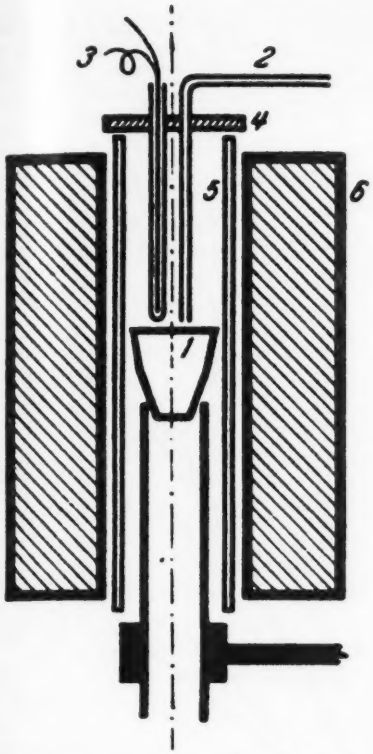

Figure 2—Apparatus for rapid testing for attack by V_2O_5. Code to numbers is as follows: 1—crucible for specimens, 2—oxygen inlet tube, 3—thermocouple, 4—asbestos seal, 5—protective tube, 6—tubular furnace.

have to be shown in the readily-oxidizable metals to at least the same degree as in chromium steel. However, the readily-oxidizable metals show only slight differences in the numbers representing the attack. The slagging effect, on the other hand, must be reflected above all in the case of the resistant alloys because of the continuous dissolution of the protective oxide films, whereas no deterioration is to be expected in the case of the non-protective oxides. It was precisely this which was established in the scaling tests involving immersion in molten V_2O_5. Even though these exploratory experiments permit no conclusion as to the part played by a lattice disturbance of the type mentioned by Hauffe,[4] it is still possible to conclude from them that the slagging effect is extremely important. The subsequent experiments were directed in accordance with these results.

It was necessary to develop a testing procedure to determine the behavior of the material with respect to V_2O_5 scaling after the shortest possible test periods. The testing methods heretofore described in the literature were found to be very diverse. Inasmuch as the nature of this attack was not clear, the corrosion tests were designed to approach the actual conditions of attack as closely as possible. Specimens were exposed, for example, to an oil-burner flame, with the resulting disadvantage of very scattered results. Longer test periods were needed.

It was mentioned at the outset that V_2O_5 corrosion

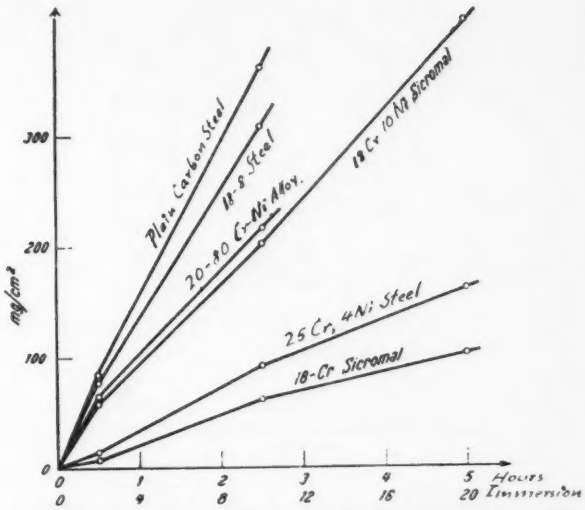

Figure 3—Weight lost by different materials during test in O_2 at 1695 F with intermittent immersion in molten V_2O_5.

involves a combined attack by the molten oxide and by oxygen. For this reason, corrosion tests in molten V_2O_5 result in a very non-uniform attack because of the varying access of oxygen. It was found, for example, that in a molten-oxide layer over 10 mm (0.4 inch) in depth, the attack upon the metal was very slight, especially if the molten oxide were not agitated. The strongest attack, on the other hand, occurred at the very surface of the molten oxide. In the authors' experiments, therefore, particular value was placed upon a uniform and well-defined temporary wetting of the specimens by the molten V_2O_5 or on their being covered with this oxide. This was attained in the testing procedure described below by adopting a certain periodicity between the attack by molten V_2O_5 and by pure oxygen.

It was possible in this manner to attain after extremely short test periods, strictly reproducible test results having a maximum deviation of ± 10 percent from the mean. This was designated as very good for so complex a corrosion phenomenon.

Testing Method

The rapid testing method will be briefly described below (Figure 2). The specimens were scaled for fifteen-minute periods in a well-defined oxygen stream at 925 C (1695 F) while being indirectly heated in a vertical tubular furnace. This made it possible to introduce and remove the specimens within a few seconds. These oxidation cycles were interrupted by brief immersions in molten V_2O_5 (at 900 C = 1650 F). This intermittent treatment can be continued as long as desired, being limited only by the complete destruction of the specimens. Furthermore, the weight loss after the individual cycles can be numerically followed. It is true that this necessitates removal of the scale layer. It was advantageous to effect the scale removal by a water quench, as a result of which most of the scale cracks off, followed by an immersion in $KMnO_4$-containing fused NaOH.

The results of these tests are illustrated by a few

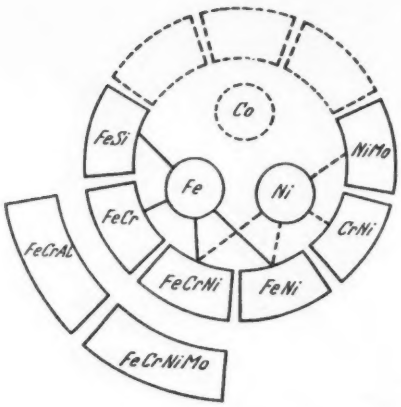

Figure 4—Comparatively tested Fe and Ni-base materials.

examples shown in Figure 3. This testing method achieves a perfectly uniform attack, which is nearly linear with time. A fairly accurate picture of the stability of the test material is already obtained after two cycles (i.e., after 30 minutes of total scaling). The weight loss was determined for the second time after ten cycles (i.e., after 2.5 hours) and an additional weighing was performed after 20 cycles (i.e., after 5 hours). Only the most resistant materials could be exposed to a five-hour long attack.

The following remarks should be made in connection with the test conditions themselves. While the test temperature of 925 C (1695 F) probably should be regarded as the upper temperature limit encountered in gas turbines utilizing currently employed materials of construction, this temperature does not represent an extremely severe condition deviating from the natural conditions of attack. The use of pure oxygen and 100 percent V_2O_5 greatly accelerates the corrosive reaction, but probably does not fundamentally affect it. The periodic immersion in molten V_2O_5 causes an extreme aggravation of the attack. Here, too, however, it is only the slagging that is deliberately promoted without introducing a new corrosive reaction not occurring in actual operation.

The choice of fifteen-minute cycles is, of course, arbitrary. It was found that these scaling periods gave the strongest and most uniform attack. The weight-loss determination after the second, tenth, and twentieth immersions is likewise arbitrary. But the nearly linear attack-time curves show that this does not basically affect the corrosion.

The oxygen-stream velocity admittedly plays an extremely vital part in giving reproducible test results. It is interesting to note that the strongest attack occurs at relatively low oxygen-stream velocities. An oxygen feed rate of 12.5 cm^3 per minute was employed.

Comparative Studies

With the aid of this reproducible rapid testing method, comparative studies were made of known scaling-resistant structural materials with an iron or nickel base, as far as specimens of such materials were available (Figure 4). The tests also were extended to include binary alloys, for example iron-nickel and iron-silicon, which as such cannot be considered as scaling-resistant materials. These tests were made to obtain better information on the effects of the individual alloying elements and are still in progress. Suitable molybdenum-free specimens were not available among the cobalt alloys. Among the very important iron-free chromium-nickel materials, it was not possible to obtain the new Nimonic alloys with increased contents of titanium and aluminum. The results obtained to date already have made it possible, however, to establish the standing of individual alloy groups with respect to their stability.

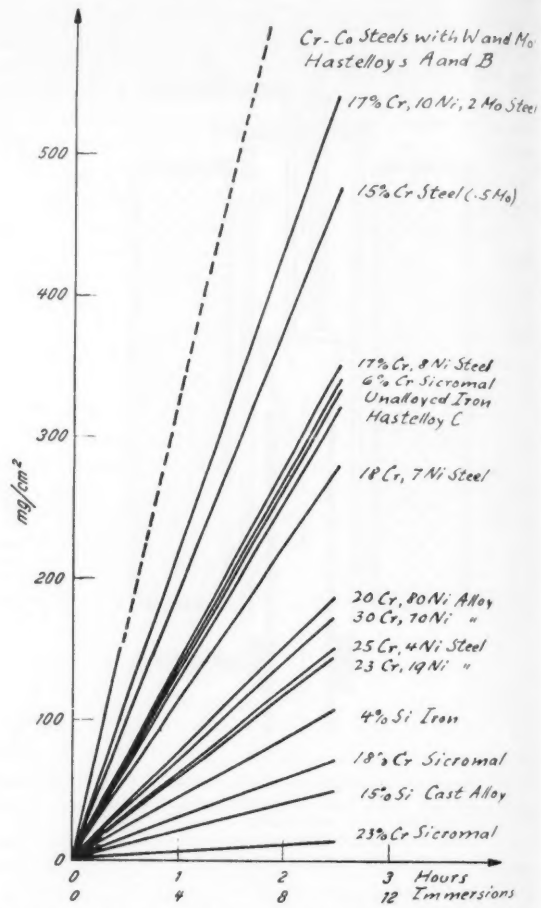

Figure 5—Scaling behavior of various materials under action of V_2O_5 according to rapid test.

Figure 5 shows the weight losses after various test periods. Maximum resistance was displayed by Sicromal 12, a ferritic 23 percent Cr steel with aluminum and about 3 percent of added silicon. Very good resistance also was exhibited by the Fe-Si cast alloy containing 15 percent Si. Because of the danger of spalling during cooling, it was difficult to test this alloy, which is known to be particularly sensitive to (fluctuating) thermal shock. The behavior of Sicromal 10 with 10 percent Cr and 2 percent Si is already somewhat poorer; it is more or less similar to that of the chromium-free iron-silicon alloy with 4 percent Si (electrical sheet).

The next group comprises the known scaling-resistant ferritic and austenitic chromium steels and chromium-nickel alloys. It is seen that 30-70 nickel-iron falls into this same group.

The alloys in the third group, which includes the 18-8 Cr-Ni steels, already scale like unalloyed iron. Hastelloy C behaves in a similar manner.

The last group of alloys comprises all alloys containing, in addition to chromium, some molybdenum as well (in part only small quantities of the latter). Examples of this are 15 percent Cr steel with 1 percent Mo, 17-10 Cr-Ni with 2 percent Mo, Hastelloy A and B, and various Fe-Cr-Co alloys with Mo and/or W.

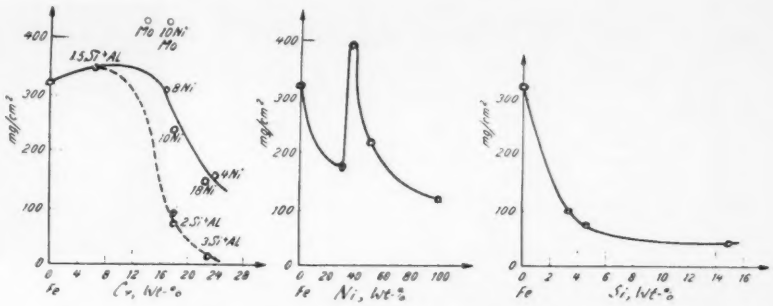

Figure 6—Effect of Cr, Ni and Si on scaling by V_2O_5.

The deleterious effect of even small quantities of molybdenum is so pronounced that an unspecified molybdenum content of 0.5 percent in a Cr steel could immediately be detected from the scaling behavior of the alloy.

This summary shows that the resistance against V_2O_5 scaling does not parallel the resistance against attack by pure oxygen. The following conclusions can be drawn from the dissimilar behavior of the materials tested: (1) silicon has a very good influence, (2) chromium has a considerably less favorable influence, and (3) molybdenum and tungsten cause catastrophic deterioration.

Generally speaking, a corrosive attack can be characterized by the weight loss only if the wear occurs uniformly over the entire surface. It could be consistently observed that such a uniform attack is exerted by V_2O_5 scaling upon iron-base alloys. In contrast with this, the attack upon nickel and nickel alloys occurs preferentially along the intergranular boundaries and leads to the breaking out of entire crystal grains.

Effects of Chromium, Nickel and Silicon

The effects of chromium, nickel, and silicon upon the resistance of iron are represented graphically in Figure 6. Chromium acts only when present in relatively large proportions; the solid curve shows the alloys with nickel, while the broken curve shows silicon-containing chromium steels. The improvement brought about by silicon is clearly recognized, while nickel probably exerts no effect, as indicated by the identical behavior of 25 percent Cr steels with 4 percent and 18 percent of nickel. In testing the effect of nickel in chromium-free Fe-Ni alloys, it was found that pure nickel behaves somewhat better than iron. The alloys with 25 percent and 45 percent nickel are approximately intermediate between the two, and only the Invar alloy exhibits an unexplained high sensitivity to attack. The clearest effect is exerted by silicon. Even small proportions of that material have a decisively beneficial effect, while only a slight additional increase in resistance is attained in the presence of more than about 6 percent silicon.

The favorable effect of silicon appears to be based on the absolute resistance of SiO_2 or silicate layers to attack by molten V_2O_5, whereas in the case of chromium alloys the carrier of the scaling resistance (i.e., the stable oxide layer) is destroyed by the formation of low-melting chromium vanadates and/or iron-chromium vanadates. This explanation is also in agreement with the known basic behavior of heavy-metal oxides and of trivalent chromium. SiO_2, on the other hand, acts as a stronger acid than V_2O_5 and is stable in the molten vanadate. On the basis of these results, it should be possible to find more resistant alloys by increasing the silicon content, whereas an increase in the chromium content gives only a delay in the attack by V_2O_5.

It was difficult to verify this reasoning experimentally because, as is known, such alloys with an increased chromium and silicon content are not in use on account of their poor deformability. In addition to that they develop a brittle phase.

A way out of this difficulty was found by alloying the known chromium steels, which were resistant to the formation of sigma phase, with increasing proportions of Cr and Si on their surface only. This alloying was effected by diffusion in the solid state. By using diffusion alloys of various concentrations, the surface of the specimens could be enriched to the desired alloy content. If use were made of a diffusion alloy capable of forming solid solutions with the specimen, the progress of the diffusion could be numerically estimated by assuming a concentration-independent coefficient of diffusion and a diffusion symmetrical with respect to the original boundary surface. These assumptions are still more or less justified for the diffusion of chromium in iron. The diffusion of silicon in iron and iron alloys, however, deviates greatly from these relationships. Altogether, the impregnation of iron with silicon by diffusion encounters a number of fundamental difficulties, which will be discussed in more detail in a subsequent communication.[6]

The corrosion behavior of such surface-alloyed steels has fully confirmed the authors' expectations. Figure 7 illustrates the slight improvement of 18-8 Cr-Ni steel by chromium impregnation and its substantial improvement by the introduction of increasing proportions of silicon. This behavior is illustrated still more clearly by Figure 8. After five hours of scaling in oxygen at 925 C (1695 F) and intermittent

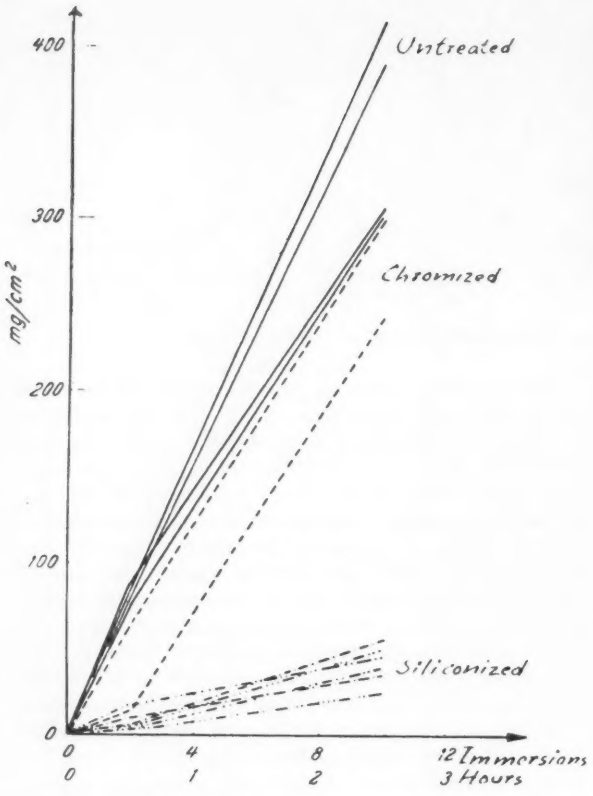

Figure 7—Weight lost by untreated, chromized and siliconized 18-8 steel due to V_2O_5 attack.

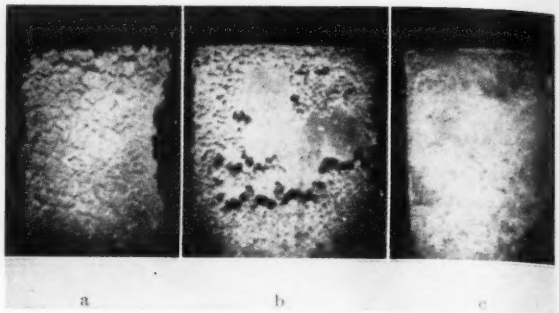

Figure 8—V_2O_5 attack (2.5 hours) at 925 C (1695 F) on (a) Untreated, (b) Chromized and (c) Siliconized 15 percent Cr steel.

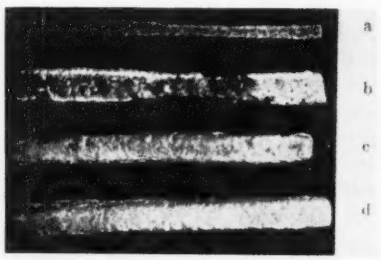

Figure 9—Twenty-three percent Cr, 20 percent Ni steel after five hours of V_2O_5 attack. Code is as follows: (a) Untreated, (b) Chromized, and (c, d) Impregnated with increasing amounts of silicon.

immersion in V_2O_5, the untreated 15 percent Cr steel shows the effects of a strong attack on all sides. Figure 8-b reveals the more resistant surface layer of the chromium-impregnated 15 percent Cr steel exposed to the same corrosive conditions, as well as the strong attack beneath this outer layer (i.e., in the zones with a somewhat lower chromium content). Figure 8-c shows the same steel with a silicon-containing surface layer. No attack at all is apparent.

The strong attack by V_2O_5, the only slight improvement resulting from an increase in the chromium content, and the decisive protective effect of silicon enrichment are clearly illustrated in Figure 9. The metal there is a 23-30 Cr-Ni steel (i.e., a highly scaling-resistant austenitic alloy). All specimens had the same thickness (2 mm = 0.08 inch) before the five-hour corrosion test. It is seen that the untreated alloy is strongly attacked on all sides (Figure 9-a). Figure 9-b shows the same alloy, but chromium-impregnated. Here, too, the strong attack under the surface layer is apparent. The two specimens shown at the bottom of Figure 9 are surface-impregnated with increasing proportions of silicon.

These interesting results will not be discussed in detail in the present communication. The description of the diffusion behavior of silicon in chromium steels and chromium-nickel steels and alloys, as well as of the properties of these surface layers, is reserved for a subsequent communication. However, the authors believe they have shown that the corrosion problem involved in V_2O_5 scaling can be solved, at least in part, by the metallurgical approach. Other possibilities of eliminating this corrosion that have recently been discussed include removal of vanadium from the fuel oils and the addition to the latter of compounds capable of preventing the deposition of low-melting oxides.

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The Relation of Thin Films to Corrosion*

By THOR N. RHODIN*

Abstract

Recent studies of thin oxide films isolated from stainless steels and other ferrous alloys have provided new information on surface properties. Correlations between the unique compositional and structural properties of thin films and alloy corrosion behavior in various corrosive environments have been established.

Evaluation of the resistance to pitting corrosion of silicon-modified Type 316L stainless steel is described as a typical example of an application of a film study to corrosion research. In this case, improved corrosion behavior was correlated with a mutual film-enrichment of silicon and molybdenum and a film-depletion of iron. Experimental alloys of improved purity were prepared and evaluated. Effects of alloy purity, carbon content, and alloying additions were found to influence strongly surface behavior and corrosion resistance.

The mechanism of resistance to pitting corrosion and the protective nature of the associated oxide films are interpreted in terms of the chemistry of hydrated heteropoly acids containing oxides of silicon and molybdenum. **3.8.4**

1. Introduction

A. Significance of Film Studies

COMMERCIAL ALLOYS contain many components which influence their chemical and mechanical properties in a complicated manner. Certain of the alloying constituents are considerably more surface-modifying than others (i.e., they are selectively enriched on the surface when the alloy is exposed to a corrosive environment.(1)) In applications where the effects of corrosion are limited essentially to a thin reaction layer at or near the surface this type of redistribution of the elements between the interior of a metal and its surface can influence markedly the surface properties of the metal.

An approach to understanding the mechanisms of corrosion reactions must provide adequate consideration of the unique properties of these surface films which inevitably result from the exposure of most metals to liquid or gaseous environments. The films reflect their parent metal in many ways. They not only undergo compositional changes but also vary considerably with reference to state of oxidation, compound formation, state of hydration, mechanical continuity, adherence, surface texture, and degree of crystallinity. All of these factors characterize the metal surface and reflect the inherent capacity of the metal to mitigate the damaging effects of its environment.

B. Factors Associated with Properties of Films

Thin films are sensitively influenced by such factors as alloy composition, corroding medium, and the conditions of exposure. Correlation of these factors with film character provides an insight into the mechanisms of surface reactions. This knowledge, in turn, establishes an effective guide for the development of improved, or, in some cases, new alloy compositions. The film-study approach has been applied successfully to the development of stainless steels with superior corrosion resistance and will be referred to later in more detail.

The object of this paper will be to provide a background on film studies and to describe some specific examples where they have provided a practical basis for achieving improved alloy performance. No effort will be made to review all surface films nor to consider films other than those of metal oxides. In addition, discussion of metal oxide films will be based primarily on compositional properties. Examples will be drawn from research at the Engineering Research Laboratory on the corrosion of stainless steels immersed in aqueous acid solutions at moderate temperatures. Most of the conclusions will refer to that particular class of oxide film which is characteristic of these conditions. Three general topics will be considered:

1. Unique properties of oxide films.
2. Film properties and corrosion behavior.
3. Evaluation of an improved alloy.

2. Unique Properties of Oxide Films

A. Classification of Oxide Films

The Generalized Film Theory[1,2] postulates that corrosion-resistant surfaces of metals are characterized by oxide films of unique compositional and structural properties. The validity of this theory requires a recognition that oxide films may vary greatly in character and function.

1. Types of Oxide Films. Distinction must be made among types of oxide films normally encountered in corrosion systems. Three of the most important parameters defining film properties are film thickness, film structure, and film composition. A class of films typical of surfaces of ferrous alloys exposed to mild oxidizing conditions in acid solutions is of particular significance. It will be referred to as Type 1. One of the most distinctive properties of this film type is its gel-like character. This is illustrated in the electron micrographs of Figure 1, in which a comparison is made between Type 1 and Type 2 films. In comparison, Type 2 films are associated with oxidation at higher temperatures and more aggressive oxidation

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* Research Project Engineer, Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Company, Inc.

(1) Referred to later as concept of surface-modifiers.

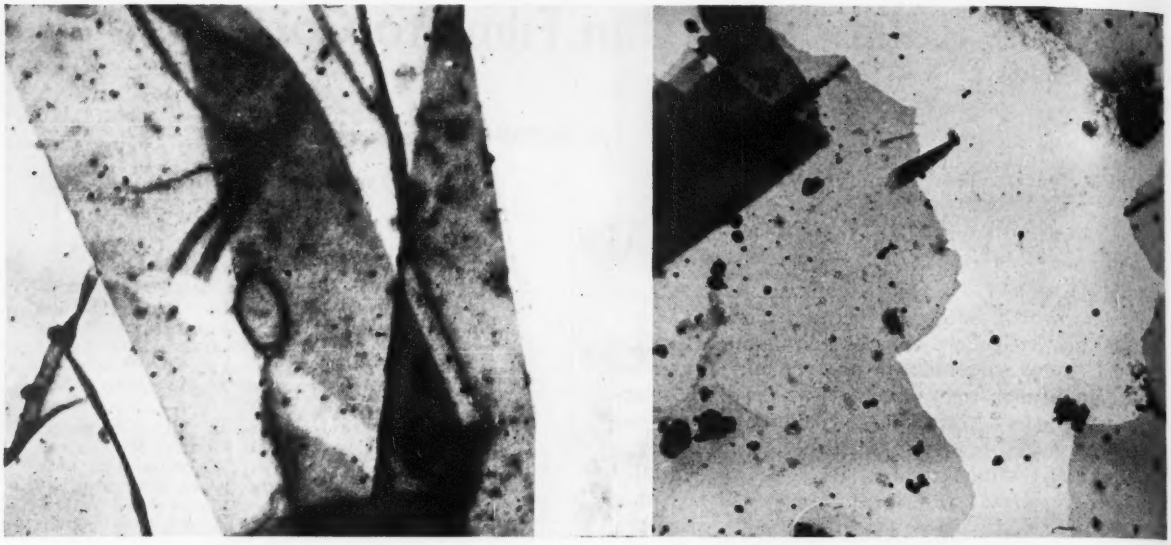

Figure 1—Electron micrographs of Type 1 (left) and Type 2 (right) oxide films isolated from surfaces of Type 316 stainless steel. Magnification, 18,500 X.

conditions and show an absence of gel-like character.[3, 4, 5, 6]

Although classification of film types must be somewhat arbitrary because of the wide range in film properties, a summarized description of the film types is proposed in Table 1 to provide a basis of comparison. Type 3 films are included for comparison but will not be discussed further here because, in the opinion of the author, they are not properly classed as thin films.

2. Significance of Film Thickness. Distinction between film types also is reflected in terms of film thickness. The importance of this is best exemplified by variations in the associated corrosion resistance. The example in Figure 2 summarizes a correlation between the two variables, thickness and corrosion resistance, in terms of weight loss in 10 percent $FeCl_3$ solution. Films of both Type 1 and Type 2 were produced on Type 304 stainless steel by a treatment in 5 percent HNO_3—0.5 percent $K_2Cr_2O_7$ solution at 60 C for various immersion periods from 1 to 300 minutes. This treatment was preceded by a bright pickle with 10 percent HNO_3—2 percent HF—1 percent HCl solution at 80 C. Typical Type 1 films could be reproducibly prepared by this two-stage method using a 30-minute immersion in the nitric acid medium. Typical Type 2 films were prepared using a longer immersion time (greater than 200 minutes) or heat-tinting in a 50 percent KNO_3—50 percent $NaNO_3$ melt at 300 C or in dry air at 100 C. Films prepared in the former manner were used as a basis for comparison among different alloy compositions.

It is evident in Figure 2 that the ultrathin Type 1 film is associated with a resistance to corrosion of approximately 10 times that typical of the Type 2 film. This example illustrates how film thickness is intrinsically related to film character and can be used as an index to predict the corrosion behavior of an alloy. It is, of course, not an adequate index to corrosion by itself, and must be related to the compositional properties of the films. The latter is probably the most useful single characteristic of films. This is particularly true for the Type 1 variety.

3. Compositional Properties. Compositional properties are best described by consideration of some typical compositions of oxide films corresponding to Type 1 and Type 2, isolated from Types 304, 316, and 347 stainless steels. Typical data are summarized in Table 3 for the compositions of the alloys and in Table 2 for the compositions of the corresponding films. Special sampling and analytical techniques, developed to obtain the film data, are described elsewhere[7, 8] and will not be reviewed here.

According to the concept of surface-modifiers as previously defined, the most significant observation is the film-enrichment of silicon, molybdenum, and niobium. The second significant observation is the distinct chromium enrichment and iron depletion characteristic of the Type 2 films. More detailed consideration of these data and the merits of the associated analytical methods can be found in references 4 and 8. The fact that the former enrichment effect is more characteristic of Type 1 than Type 2 films is illustrated in Figure 3 for surface treatments associated with the production of these two film types on Types 316 and 347 stainless steels. It should be noted that these data are reported on the basis of a water-free film sample. Actually, up to 30 percent water is often observed to be strongly bound to the oxides in the Type 1 films.[4, 7, 9] Film-compositional data are reported on the basis of the dehydrated film-sample weight for convenience. Reference to metal contents is made on the assumption that the metals are combined as stoichiometric oxides. Although this assumption is not completely true the uncertainty introduced is not critical in this discussion.

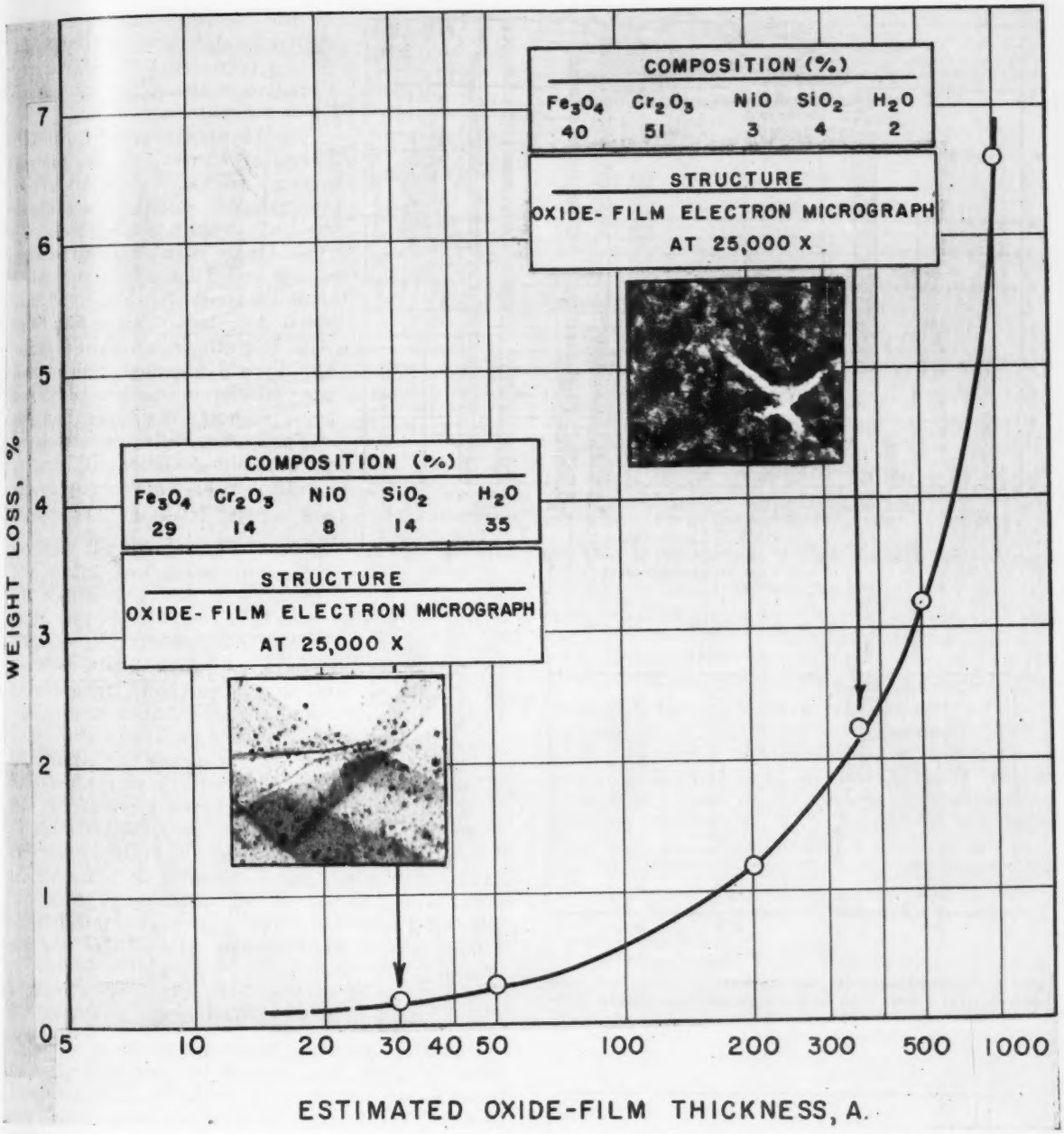

Figure 2—Effect of film thickness on the properties and behavior of oxide film on Type 304 stainless steel. Weight loss in 10 percent $FeCl_3$ solution at 25 C after 144 hours.

B. Compositional Relationships of Films

1. **Stainless Steel Alloys.** In addition to distinctions among types of films, film compositions also are characterized by unique interrelationships among different elements in the same type of film. An illustration of this is found in Figure 4, in which the silicon and molybdenum contents of films isolated from austenitic stainless steels are correlated with variations of silicon and molybdenum in the alloys. Compositions of these alloys are listed in Table 3. Although these films also contain other components such as chromium, nickel, oxygen, and water, the most important film-modifying elements in this case are silicon and molybdenum. They interact to promote substantial film enrichment of each other.

This effect is striking for a silicon-modified Type 316L[2] stainless steel (designated as SP-2), an experimental alloy with superior resistance to pitting corrosion originated by Streicher.[10] The Type 1 films referred to in Figure 4 also are characterized by a typical depletion of iron as indicated in Figure 5 for Types 316, 302B, and SP-2 stainless steels. This trend

[2] It should be noted that the high nitrogen content of this alloy (0.23 percent) also probably influences its corrosion resistance. The effect of this factor on film properties remains to be evaluated.

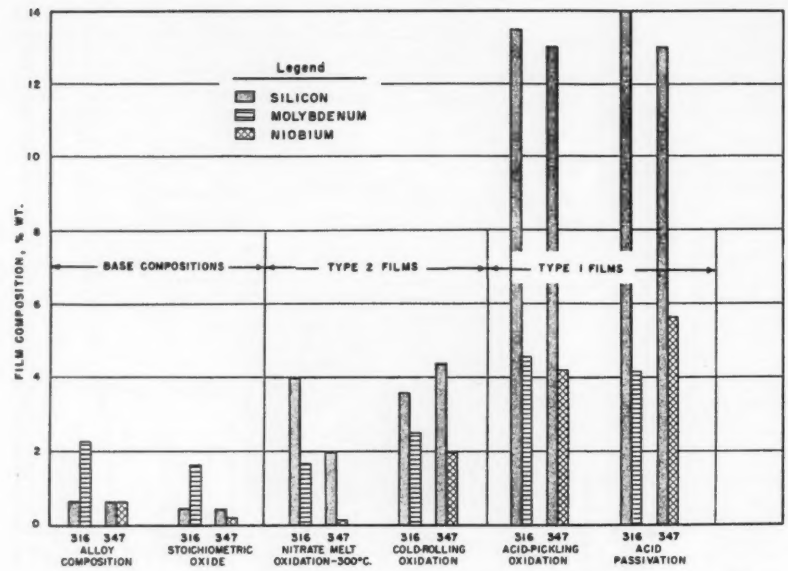

Figure 3—Effect of surface treatment on composition of oxide films isolated from Type 316 and Type 347 stainless steel.

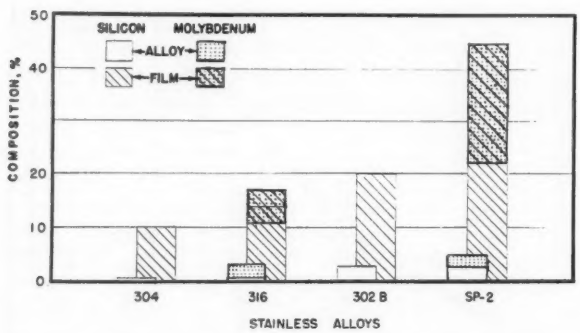

Figure 4—Relationship between film-enrichment of silicon and molybdenum for Type 1 oxide films isolated from austenitic stainless alloys.

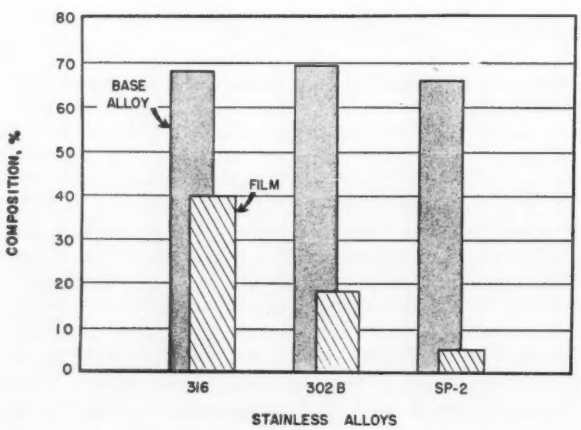

Figure 5—Relationship between film-depletion of iron and alloy composition for Type 1 oxide films isolated from austenitic stainless alloys.

in iron content of the film varies systematically with resistance to pitting corrosion and will be referred to in the following section on corrosion behavior.

The interrelationship of the three elements, silicon, molybdenum, and iron in films from molybdenum-modified stainless steel alloys with and without silicon addition is summarized in Figure 6 for Type 316L and SP-2 stainless steels. It is observed that the iron depletion for the film from SP-2 is much greater than that for the Type 316L alloy. Silicon and molybdenum in stainless alloys not only promoted their own film enrichment but also are associated with a film-depletion of iron. A mechanism by which this may occur is suggested in the next section.

2. Other Ferrous Alloys. Film relationships among iron, silicon, and molybdenum are not unique for stainless alloys but also have been observed for other ferrous alloys containing these elements. For example, comparison of composition for Type 1 film between SP-2 stainless steel and "Durichlor," indicated in Figure 7, shows a similar redistribution of iron, silicon, and molybdenum between the alloy and the film. It may be concluded that the excellent resistance of "Durichlor" to the halogen acids is associated with its unique film properties. The marked similarity in film properties between these two very dissimilar alloys indicates a closer relationship in their surface behavior than would be predicted from conventional metallurgical considerations. Additional generalizations with reference to the relationships among Type 1 films may develop as more data of this kind are obtained.

C. Comparison of Wet and Dry Oxidation

It is also important to determine the relationship between oxide films formed by oxidizing acids to those formed by gaseous oxidation. Compositional data on Type 1 and Type 2 films isolated from Type 304 stainless steels can be used for comparison. The

TABLE 1—Classification of Oxide Films[1] on Ferrous Alloys

	Type 1	Type 2	Type 3
Thickness (Angstroms)	Approximately 25	More than 300	Not less than 1000
Appearance	Transport	Colored	Opaque
Physical Properties	Gel-like	Pseudomorphic	Recrystallized
Structure	Amorphous and homogeneous	Brittle crystalline layers	Stratified bulk oxides
Composition	Hydrated polyacids (for example $FeO \cdot Cr_2O_3 \cdot SiO_2 \cdot H_2O$)	Homogeneous enrichment of refractory oxides	Heterogeneous enrichment of refractory oxides
Conditions of Formation	Mild gaseous or liquid oxidizing condition (below 100 C)	Oxidation under moderate conditions (below 500 C)	High-temperature oxidation (above 500 C)

[1] Typical properties chosen to provide a basis for comparison and are not intended to represent exact values.

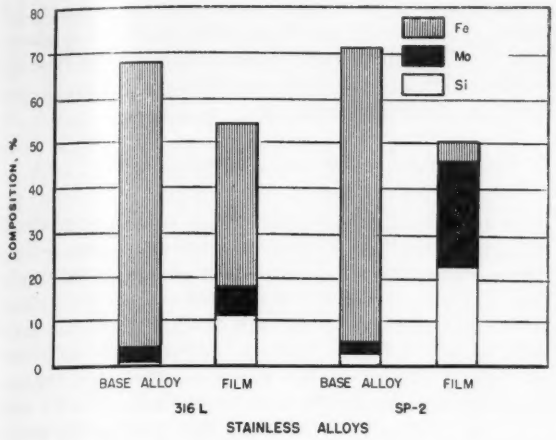

Figure 6—Comparison of film-enrichment and film-depletion for Type 1 oxide films between Type 316L and SP-2 stainless steels.

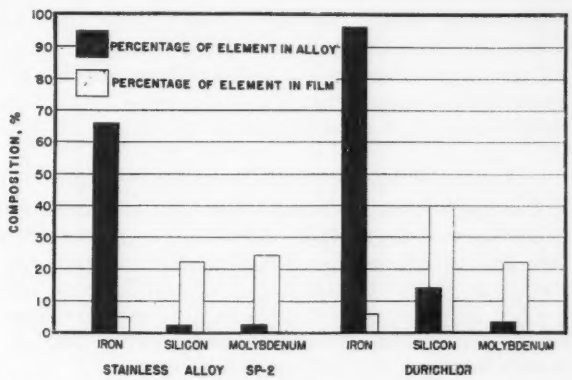

Figure 7—Comparison of film-enrichment and film-depletion for Type 1 oxide films between Type SP-2 stainless steel and "Durichlor."

oxidizing acid treatment used involved the 5 percent HNO_3—0.5 percent $K_2Cr_2O_7$ treatment described previously, or treatment in 5 percent H_2SO_4 at 100 C as indicated.

The gaseous oxidation treatment was part of a special study of oxygen adsorption on passivity of stainless steel.[10] The two important factors with reference to film properties refer to preparation of the surface and measurement of the true surface-oxygen concentration. Stainless steel surfaces, essentially free of oxygen contamination, can be prepared by treatment of the sample in high vacuum (1×10^{-7} mm of mercury) for one hour at 965 C. This is referred to as an "activation" treatment since surfaces of stainless steel prepared in this manner display an unusual avidity for film formation even at very low temperatures (—195 C). The amount of film formation, measured directly in a vacuum micro-balance, was controlled by the introduction of various atmospheres such as dry oxygen, filtered air, wet oxygen (saturated with water at 25 C), or acid solutions. Samples prepared in this way were transferred in sealed glass containers to a film-stripping apparatus for film analysis.

Film data typical of both types of oxidizing media are summarized in Table 4 for eight surface treatments. The significant observation is in the general similarity between the first group (samples 1-4), corresponding to pretreatment in acids, to the second group (samples 5-8), corresponding to pretreatment in oxygen atmospheres. The lower silicon enrichments characteristic of films in the second group are consistent with the absence of an aqueous environment in the oxidation treatment. Sample 9 is included as a control and indicates that the experimental procedure used precluded the possibility of any significant amount of film formation from spurious sources.

The appreciable film enrichment of silicon characteristic of the first group is consistent with previous observations that a bright pickle in an oxidizing acid by itself, or followed by treatment in hot, dilute nitric acid, promotes enrichment of silicon in Type 1 film. The chromium enrichment found in the thicker films (samples 7 and 8) is similar to that reported[6] for Type 2 films formed in oxidizing acids (also, see Figure 2 and Table 2).

In addition, water is observed to be an important component of the Type 1 films if the surface has been exposed to an environment containing water. This is true whether the water-exposure occurs during pretreatment, oxidation, or after oxidation, indicating that the striking capacity of Type 1 films for the

TABLE 2—Comparison of X-Ray and Chemical Analytical Data for Oxide Films Isolated From Austenitic Stainless Steels (Sample Size, 25 — 100 x 10^{-6} g.)

Oxide Film Type	Nature of Film Sample	Analytical Method	Fe		Cr		Ni		Si		Nb		Mo	
			%[1]	S.D.[2]	%	S.D.	%	S.D.	%	S.D.	%	S.D.	%	S.D.
1	Type 304 Oxide	X-Ray	37.2	4.0	13.4	2.0	9.4	1.2	....	....	....	....	....	....
	Thickness, 30 Å	Chemical	34.0	3.1	14.0	3.4	10.7	4.0	9.9	2.0	....	....	....	....
1	Type 316 Oxide	X-Ray	42.1	3.2	12.6	0.7	4.9	0.6	....	....	....	....	(1.2)	....
	Thickness, 30 Å	Chemical	45.0	4.2	13.0	2.0	5.4	2.1	14.5	3.2	....	....	4.2	1.1
1	Type 347 Oxide	X-Ray	45.4	4.2	17.7	3.0	7.7	0.8	....	....	(3.0)	....	(0.1)	....
	Thickness, 30 Å	Chemical	44.5	5.0	20.7	3.2	8.2	2.6	12.9	3.2	5.7	1.0	0.4	0.1
2	Type 304 Oxide	X-Ray	15.0	2.0	45.5	3.7	3.8	0.2	....	....	....	....	....	....
	Thickness, 300 Å	Chemical	15.1	2.6	46.6	5.0	4.0	0.5	3.3	0.1	....	....	....	....
2	Type 316 Oxide	X-Ray	25.0	3.2	36.8	3.1	5.0	0.3	....	....	....	....	(0.2)	....
	Thickness, 300 Å	Chemical	25.2	4.0	36.1	4.3	5.2	0.8	4.0	0.3	....	....	1.6	0.3
2	Type 347 Oxide	X-Ray	24.8	2.8	36.1	2.1	2.2	0.1	....	....	....	....	....	....
	Thickness, 300 Å	Chemical	25.0	3.2	35.2	4.1	2.2	0.1	2.0	0.2	1.2	....	0.3	....

[1] Percent by weight. [2] Standard deviation.

adsorption and retention of water is an intrinsic characteristic of this class of oxide film. This is in agreement with earlier work of Fontana[8] on hydrated metal oxide films. The over-all conclusion may be made that, except for secondary variations typical of the aggressiveness of the oxidizing media, the compositional properties of oxide films formed in oxidizing acids or gaseous oxygen are closely related.

3. Film Properties and Corrosion Behavior

The mechanisms by which films form and maintain themselves on the surfaces of metals provide an effective approach towards understanding corrosion behavior in many applications. The usefulness of film studies depends, however, on an adequate definition of the relationship between film properties and corrosion behavior for each corrosion system.

A. Influence of Corrosion Environment on Film Properties

Definition of this relationship for three typical acid solutions, 5 percent H_2SO_4, 10 percent HNO_3, and 10 percent $FeCl_3$, for Type 304 stainless steel, summarized in Figure 8, illustrates the point.

There are two features of particular significance depicted in Figure 8. First, the proportions of iron, nickel, chromium, and silicon in the protective films for each medium are different from each other but characteristic of each acid. Second, there is a definite trend in the film composition with time of immersion for a given medium. In other words, the film properties reflect sensitively the corrosive environment and are changing continuously as if processes of deposition and dissolution were proceeding simultaneously.

In some cases (10 percent $FeCl_3$, Figure 8) this is associated with compositional properties reflecting an approximately steady-state condition. In other cases, the equilibrium between film and corrodent may shift considerably (5 percent H_2SO_4, Figure 8). For example, examination of the sample surface for the test in 5 percent H_2SO_4 indicated that passivity had broken down and that the corrosion process had changed considerably between the film samples corresponding to the immersion periods, 0.5 and 2.0 hours. Interpretation of the discontinuity in variation of film composition observed for these two immersion periods must be considered in terms of two different corrosion processes.

B. Effect of Alloy and Film Composition on Pitting Corrosion

In addition to the nature of the corrosive medium, film properties also depend on alloy composition. Corrosion resistance is observed to vary systematically with silicon content for Types 304 and 304L stainless steels immersed in 10 percent $FeCl_3$ solution at 25 C, as indicated in Figure 9. Both the intensity and extent of pitting attack under these conditions increases considerably for alloys containing less than 0.4 percent silicon. It also is observed that greater resistance to corrosion occurs in the extra-low-carbon alloys. The latter effect has been reported previously by Streicher.[10]

These results may be interpreted in terms of variations in film composition, as indicated in Figure 10. Correlation is shown between corrosion weight loss and film-silicon and alloy-silicon contents for two sets of Type 304L stainless steels, designated as commercial and experimental alloys. The former are typical of commercial melting and fabrication practices. The latter were prepared in the laboratory and represent material of more controlled composition and improved purity.

Compositions of the commercial alloys are listed in Tables 3 and 5, respectively, and compositions of the experimental alloys are listed in Table 6. It should be noted that the experimental melts were heat-treated and fabricated to yield material of a comparable metallurgical character to the commercial alloys except for the compositional differences indicated.

The following features in Figure 10 should be noted. Weight loss decreased rapidly for the commercial alloys as the silicon content of the film approached 8 to 10 percent. It is interesting to note that this is the value generally observed for Type 1 films on pickled commercial Type 304L stainless steels of

TABLE 3—Alloy Compositions[1] and Corrosion Rates
(Tested in 10 Percent $FeCl_3$ at 25 C)

Alloy No.	Type	Designation	% Cr	% Ni	% Si	% C	% Mn	% S	% Mo	% Nb	Corrosion Rate mg/sq cm/day
A-1	Commercial Austenitic Stainless Steels[2]	Type 304	18.6	10.7	0.49	0.05	1.54	0.019	....	....	1.81
A-2	Commercial Austenitic Stainless Steels[2]	Type 316	17.6	13.0	0.60	0.08	0.77	0.006	2.3	....	0.10
A-3	Commercial Austenitic Stainless Steels[2]	Type 347	18.2	10.8	0.64	0.04	1.30	0.009	0.2	0.64	0.12
B-1	Commercial Type 304 Stainless Steel[3]	Type 304	18.6	9.4	0.26	0.05	0.90	0.019	....	....	2.82
B-2	Commercial Type 304 Stainless Steel[3]	Type 304	18.4	8.8	0.29	0.06	0.59	0.025	....	....	2.92
B-3	Commercial Type 304 Stainless Steel[3]	Type 304	17.6	10.1	0.41	0.06	1.73	0.014	....	....	2.00
B-4	Commercial Type 304 Stainless Steel[3]	Type 304	18.6	10.7	0.49	0.05	1.54	0.019	....	....	1.81
B-5	Commercial Type 304 Stainless Steel[3]	Type 304	18.3	8.7	0.61	0.07	0.75	0.008	....	....	1.62
B-6	Commercial Type 304 Stainless Steel[3]	Type 304	18.4	9.9	0.66	0.07	....	....	....	....	0.42
B-7	Commercial Type 304 Stainless Steel[3]	Type 304	17.9	8.6	0.88	0.09	0.85	0.015	....	....	0.38
B-8	Commercial Type 304 Stainless Steel[3]	Type 304	19.9	9.6	1.56	0.08	1.25	0.012	....	....	0.42
B-9	Commercial Type 304 Stainless Steel[3]	Type 304	18.2	8.8	1.89	0.09	0.92	0.014	....	....	0.32
B-10	Commercial Type 304 Stainless Steel[3]	Type 304	19.6	9.0	2.02	0.05	0.89	0.010	....	....	0.39
...	Miscellaneous Alloys[4]	Type SP-2[5]	18.79	9.25	2.50	0.04	0.77	....	2.40	....	0.01
...	Miscellaneous Alloys[4]	"Durichlor"	....	....	14.50	0.85	....	....	3.10	....	.....

[1] Balance iron in all cases.
[2] See Table 2 for compositional data on corresponding oxide films.
[3] See Figures 9 and 10 for corresponding data on film compositions and corrosion data.
[4] See Figures 6 and 7 for compositional data on corresponding oxide films.
[5] Type SP-2 alloy contains 0.23 percent nitrogen.

average composition. Film studies on a large number of typical 18-8 stainless steels indicate that relatively good corrosion resistance in 10 percent $FeCl_3$ solution is associated with a film enrichment in silicon of this order. It is observed also that film-silicon approaches this optimum value at much lower alloy-silicon levels for the experimental alloys. This indicates that the availability of silicon for film formation is greater in the purer experimental material.

A similar effect, not indicated here, also is true for the extra-low-carbon grade compared to the normal carbon grade of commercial Type 304 stainless steel. The improved availability of silicon for the experimental alloy is perhaps explained by a larger portion of the silicon present in the commercial alloy being combined as oxide inclusions and other compounds. This interpretation is also consistent with the fact that the corrosion rate for the experimental alloy does not show the rapid increase typical of the commercial alloys until a much lower silicon level is reached.

It may be concluded that the improvement in resistance to pitting corrosion resulting from increased purity, and lower carbon contents, as compared to commercial Type 304 stainless steels, is associated with the formation of surface films of superior protective properties.

C. Influence of Synergistic Film Enrichment on Corrosion

The synergistic effect of silicon and molybdenum in stainless steels results in a greater mutual film enrichment of both elements and shows a corresponding effect on corrosion resistance. This correlation is indicated in Figure 11 where pit initiation in terms of the number of pits formed per unit area is plotted against the total silicon-plus-molybdenum content of the alloys as well as that of the corresponding oxide films.

Corrosion data in this case were obtained by Streicher[10] using his accelerated pitting corrosion test. He designed this test to provide an index to the initiation of pitting in contrast to other stages of pitting corrosion such as pit growth and general attack. It is observed that good corrosion resistance un-

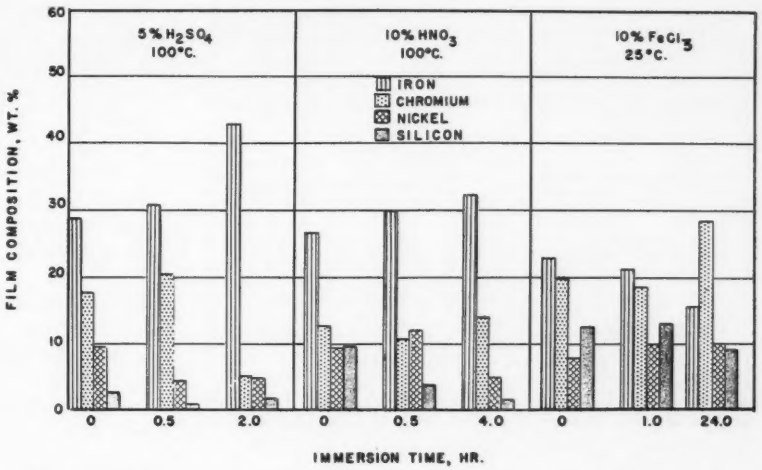

Figure 8—Effect of corrosion environment on composition of Type 1 oxide films isolated from Type 304 stainless steel. Samples tested in 10 percent $FeCl_3$ solution were pretreated in 5.0 percent HNO_3-0.5 percent $K_2Cr_2O_7$ at 60 C for 30 minutes. Note: The initial film compositions referring to zero time vary because of minor differences in pretreatments of surfaces.

TABLE 4—Composition of Oxide Films Studied in the Vacuum Microbalance[1]

Pretreatment	Oxidation	Wt., μ g./sq. cm.	% Fe	% Cr	% Ni	% Si	% O[2]
1. Acid Pickle...	5% HNO_3—0.5% $K_2Cr_2O_7$ at 60 C[3]	1.70	27.3	13.0	9.8	9.9	40.0
2. Acid Pickle...	10% HNO_3 at 60 C[3]	2.10	29.0	12.5	6.8	10.6	41.1
3. 5% H_2SO_4...	Filtered air at 25 C	1.92	36.4	10.3	9.3	4.4	39.6
4. Acid Pickle...	Filtered air at 25 C	2.62	23.2	16.2	1.2	11.5	41.9
5. Activated.....	Dry oxygen at 25 C	1.26	32.0	16.2	5.0	2.8	42.7
6. Activated.....	Wet oxygen[4] at 25 C	1.43	33.7	18.0	6.2	3.2	37.5
7. Activated.....	Dry oxygen[4] at 25 C and 5% H_2SO_4 at 25 C	3.10	25.0	26.1	10.2	2.5	33.1
8. Activated.....	Dry oxygen at 100 C	8.50	20.1	37.2	6.6	1.0	35.1
9. Activated.....	None	Less than 0.02	*	*	*	*	*

[1] Samples No. 5-9 prepared in vacuum microbalance. Data on Samples No. 1-4 from references 4 and 7. All films isolated from commercial Type 304 stainless steel (18.6 Cr—10.7 Ni—0.49 Si—0.05 C—1.54 Mn—0.019 S—Bal. Fe).
[2] Determined by difference.
[3] Unignited film contains approximately 30 percent water.
[4] Unignited film contains approximately 10 percent water.
* Sample too small to analyze.

TABLE 5—Alloy Compositions and Corrosion Rates[1]
(Tested in 10 Percent $FeCl_3$ at 25 C)

Commercial Type 304L Stainless Steel

Alloy No.	% Cr	% Ni	% Si	% C	% Mo	% Mn	% S	% O	% W	% Cu	Corrosion Rate, mg/sq cm/day
D-1.....	18.50	10.75	0.190	0.018	.....	1.501	.....	.....	.....	.....	0.81
D-2.....	19.20	9.24	0.301	0.024	.....	.....	.....	.....	.....	.....	0.42
D-3.....	18.41	9.49	0.312	0.025	.....	1.121	.....	.....	.....	.....	0.88
D-4.....	18.30	9.70	0.500	0.024	.....	1.105	.....	.....	.....	.....	0.56
D-5.....	18.34	9.40	0.565	0.023	.....	1.050	.....	.....	.....	.....	0.61
D-6.....	18.24	9.72	0.630	0.022	.....	.....	.....	.....	.....	.....	0.21
D-7.....	18.04	9.12	0.720	0.026	.....	1.110	.....	.....	.....	.....	0.15

[1] See Figures 9 and 10 for additional corrosion data and for film data.

TABLE 6—Alloy Compositions and Corrosion Rate[1]
(Tested in 10 Percent $FeCl_3$ at 25 C)

Experimental Type 304L Stainless Steel

Alloy No.	% Cr	% Ni	% Si	% C	% Mo	% Mn	% S	% O	% W	% Cu	Corrosion Rate, mg/sq cm/day
XA-8.....	17.91	9.95	0.003	0.023	.....	0.960	0.004	0.010	0.001	0.010	5.62
XA-6.....	18.02	10.15	0.006	0.029	.....	0.970	.....	.....	0.002	0.025	4.32
XA-2.....	21.97	8.25	0.082	0.013	.....	0.059	.....	.....	0.004	0.040	4.52
XA-4.....	22.88	8.12	0.038	0.012	.....	0.740	.....	.....	0.003	0.013	3.21
XA-10A...	18.22	10.23	0.052	0.037	.....	0.930	0.004	0.008	0.002	0.020	1.62
XA-13A...	17.70	9.99	0.372	0.024	.....	0.890	.....	.....	0.001	0.015	0.88
XA-3.....	22.44	8.08	0.521	0.020	.....	0.030	.....	.....	0.003	0.024	0.22
XA-5B...	18.61	9.52	0.750	0.031	.....	0.950	.....	.....	0.001	0.042	0.26
XA-12B...	17.76	8.80	1.050	0.025	.....	0.895	0.006	0.021	0.002	0.012	0.14
XA-9B...	18.05	8.50	1.620	0.018	.....	1.102	.....	.....	0.001	0.051	0.12

[1] See Figure 10 for corrosion and film data.

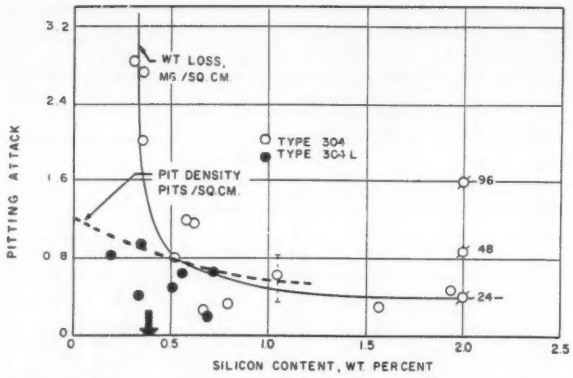

Figure 9—Effect of silicon and carbon on pitting attack of Types 304 and 304L stainless steel in 10 percent $FeCl_3$ at 25 C after 24 hours.

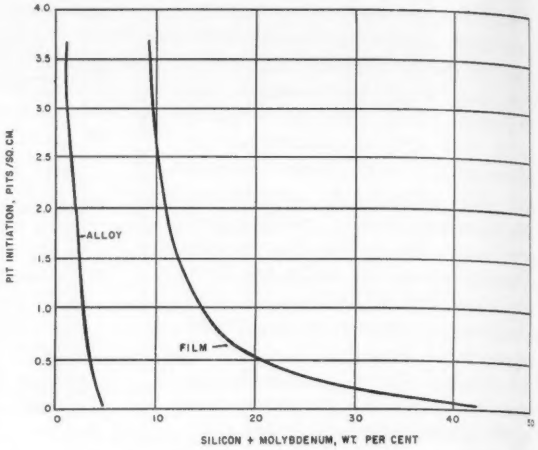

Figure 11—Effect of silicon and molybdenum enrichment in Type 1 oxide films isolated from austenitic stainless steels on pit initiation in 10 percent $FeBr_3$ at 25 C after 24 hours.

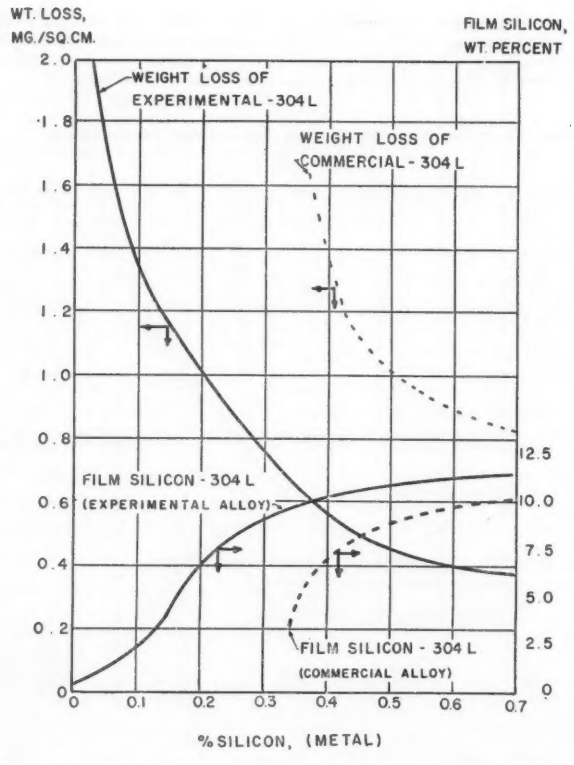
WT. LOSS, MG./SQ.CM.
FILM SILICON, WT. PERCENT
WEIGHT LOSS OF EXPERIMENTAL - 304 L
WEIGHT LOSS OF COMMERCIAL - 304 L
FILM SILICON - 304 L (EXPERIMENTAL ALLOY)
FILM SILICON - 304 L (COMMERCIAL ALLOY)
% SILICON, (METAL)

Figure 10—Effect of silicon on pitting attack and film composition of commercial and experimental Type 304L stainless steels in 10 percent $FeCl_3$ at 25 C after 24 hours.

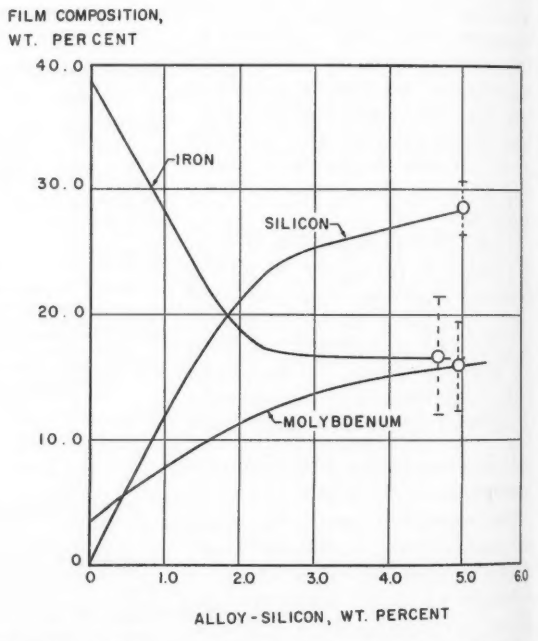

Figure 12—Initial composition of Type 1 oxide films isolated from experimental silicon-modified Type 316L stainless steels. Films formed by treatment in 5.0 percent HNO_3-0.5 percent $K_2Cr_2O_7$ at 60 C for 30 minutes.

der these conditions corresponds to film compositions containing large amounts of silicon plus molybdenum. No distinction was made in these tests between the relative amounts of the two elements in the films. However, this effect has since been studied systematically by the writer for silicon-modified Type 316L stainless steels and will be described in more detail in the following section on the relation between film properties and corrosion.

Marked film enrichment of these two elements initiates at about the 4 percent (molybdenum + silicon) level in the alloy. The mechanism of interaction between silicon and molybdenum from the viewpoint of the formation of protective films with superior properties is very interesting and probably not limited to these two elements. This interrelationship suggests a potentially useful guide to the formulation of other improved alloys. On this assumption let consideration be given to a more detailed study of the relationship between these two elements (and that of iron) with reference to film formation and corrosion resistance.

D. Film Properties and Corrosion Mechanism

The relationship between silicon, molybdenum, and

iron and its effect on mechanisms leading to protection was investigated by preparing and evaluating a series of experimental[3] Type 316L stainless steels containing silicon in the range from 0.005 percent to 5.0 percent. Compositions of these alloys are listed in Table 7. Coupon samples were prepared and pretreated using the standard pickle-passivation treatment previously described. The samples were tested in 10 percent $FeBr_3$ solution at 25 C because these conditions are known to be particularly severe for alloys of this type.

Films were isolated and analyzed from each of the alloys after pretreatment and prior to immersion in the test solution. Films also were studied for each of the same alloys after exposure to the test solution for 150 hours to evaluate the effect of corrosion on film composition. The film compositions showed significant correlations with both alloy composition and surface treatment.

Effect of alloy composition on film composition is indicated in Figure 12 for surfaces in the pretreated but unexposed condition. The chromium and nickel contents are not indicated since they accounted for less than 10 percent of the film. (Uncertainty in the data on film composition is indicated by the vertical lines at or about the 5 percent alloy-silicon level.) It is observed that film composition is influenced strongly by the silicon content of the alloy. Film-silicon increased very rapidly in the alloy-silicon range from approximately 0 to 2 percent.

Film-iron decreased rapidly in the same range. Film-molybdenum increased slowly but steadily as alloy-silicon increased up to 2.0 percent. Above approximately 2 percent alloy-silicon, variation of these three elements in the film leveled off considerably. Films in this range were composed essentially at 30 percent SiO_2, 30 percent H_2O, 20 percent MoO_4, and 10 percent Fe_2O_3 or their corresponding chemical equivalents. (There is uncertainty in defining the exact formulation of the oxides in the films.) From consideration of film properties a distinct transition in surface behavior is indicated for alloys in this series at the 2.0 percent alloy silicon level.

The influence of immersion in the test solution also shows some interesting correlations. The corresponding data on film composition for the samples after test are summarized in Figure 13. Comparison of these film data to those in Figure 12 indicates that the enrichment curves for silicon and molybdenum have been interchanged. The alloy surfaces apparently have readjusted themselves to the corrosive environment, resulting in a replacement of approximately 25 percent of the silicon by molybdenum in the protective films. This partial loss of film-silicon occurs only for those alloys containing more than approximately 1.0 percent silicon. Below this alloy-silicon level, the replacement of silicon by molybdenum in the curve is not significant.

[3] Refers to materials of controlled composition and improved purity prepared in the laboratory similar to the experimental Type 304L stainless steel alloys previously described.

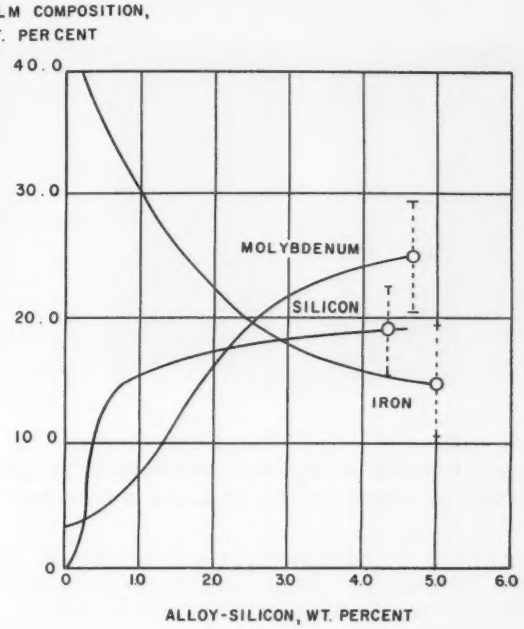

Figure 13—Final composition of Type 1 oxide films isolated from experimental silicon-modified Type 316L stainless steels after immersion in 10 percent $FeBr_3$ at 25 C for 150 hours.

It is observed that the film-iron curve is not altered significantly by immersion in the corrodent. This is consistent with the view that iron oxide is being preferentially leached out of the films in both cases. The general observation may be made that the pickle-passivation pretreatment tended to over-enrich the surface in silicon. Subsequent immersion in the corrodent partially reversed this effect, resulting in replacement of some of the film-silicon by film-molybdenum. This adjustment in film composition produced a surface of superior protective quality.

The capacity of the surface to make this adjustment apparently increased most rapidly with alloy-silicon between 1 to 2 percent (Figure 13). Silicon additions in this range would be predicted to have the most striking effect on corrosion resistance on this basis. Above 3 to 4 percent, further additions of silicon would be expected to contribute little to corrosion behavior. The approximate film compositions corresponding to alloy compositions in this range are 30 percent MoO_4, 30 percent H_2O, 25 percent SiO_2, and 10 percent Fe_2O_3. The corrosion data to be considered in the following section will indicate that optimum alloy corrosion performance was associated with protective films of this composition.

TABLE 7—Alloy Compositions and Corrosion Rates[1]
(Tested in 10 Percent $FeBr_3$ at 25 C)
Experimental Type 316L Stainless Steel

Alloy No.	% Cr	% Ni	% Si	% C	% Mo	% Mn	% S	% O	% W	% Cu	Corrosion Rate, mg/sq cm/day
XA-15....	16.90	11.91	4.67	0.031	2.14	0.90	0.003	0.012	0.002	0.025	0.012
XA-16....	16.32	11.82	2.41	0.020	1.97	1.02	.....	.....	.....	.....	0.025
XA-17....	15.41	13.21	0.76	0.024	2.04	0.85	0.004	0.010	0.005	0.012	0.064
XA-18....	14.23	13.35	0.17	0.023	2.14	0.92	.....	.....	.....	.....	0.195
XA-19....	15.55	13.05	0.005	0.018	2.10	0.98	.....	.....	.....	.....	0.460

[1] See Figures 12 and 13 for film data and Figures 14 and 15 for additional corrosion data.

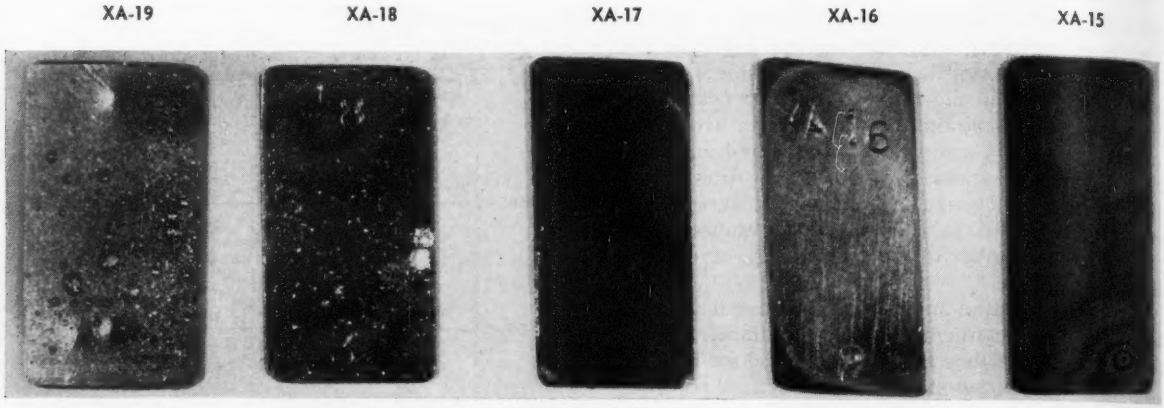

Figure 14—Samples of experimental silicon-modified Type 316L stainless steels after immersion in 10 percent $FeBr_3$ at 25 C for 150 hours. * Weight loss (MG/SQ CM) after 150 hours in 10 percent $FeBr_3$ at 25 C.

Prior to consideration of corrosion data, the relation between film properties and corrosion mechanism can be qualitatively interpreted in terms of the colloidal properties of certain heteropoly acids.[12] The chemical and physical properties of the films resemble strongly those of the heteropoly acids composed of units of SiO_2, MoO_4, and H_2O in various proportions. These acids can be thought of as derivatives of the polyacid, $H_4SiO_4 \cdot 2H_2O$, composed of a central silicon atom with a coordination number of 6, corresponding to the equivalent formula, H_8SiO_6. The oxygen atoms can be wholly or partially substituted for by radicals such as MoO_4 to yield heteropoly acids such as, for example, $H_8(SiMoO_9)$ which contains 1 MoO_4 group.

This exchange can occur readily, depending on the acidity and nature of the medium. It can produce a series of acid-derivatives, in equilibrium with each other, containing various amounts of silicon and molybdenum. The significant property, from a corrosion viewpoint, is that addition of MoO_4 groups tends to form acid derivatives less readily hydrolyzed and more readily polymerized than the parent compound.[12] These, of course, are the properties characteristic of stable, protective oxide films.

The structure and stability of the higher homologs also are sensitive to temperature, acidity, and the presence of other ions such as halides in solution. The acids form colloidal solutions which also are coagulated or dispersed in electrolytes containing heavy metal ions such as iron, molybdenum, etc. It is very reasonable that the properties of these heteropoly acids exert a strong influence on the mechanism of film formation and corrosion resistance of the silicon-modified Type 316L stainless steels. The chemistry of the heteropoly acids is relevant not only to the understanding of film mechanisms associated with these alloys but can be reasonably extended to the film properties of other surface-modifying metals such as titanium, niobium, etc.

4. Evaluation of an Improved Alloy

The practical aspects of film studies are best illustrated by consideration of the effect of silicon additions on the nature and extent of pitting corrosion of the experimental Type 316L stainless steels, the film properties of which were just described. (See Table 7 for compositions of these alloys.)

A change in the character of corrosion occurs with silicon additions at about the 2 percent level as predicted on the basis of the film properties. Photographs of the sample coupons themselves (Figure 14) after immersion in the corrodent for 150 hours provide a striking qualitative illustration of this transition in corrosion behavior. Alloys XA-19 and XA-18 have suffered intense localized attack. Alloy XA-17 is characterized by a discolored surface with isolated pitting intermediate in nature between localized and general attack, and alloys XA-16 and XA-15 have undergone a finely dispersed, evenly distributed etching of the surface associated with relatively little loss of metal.

The quantitative aspects of the corrosion pattern are more clearly indicated by the weight-loss curves in Figure 15 for the same five alloys. The corrosion rates for the first 50-hour period decrease by almost 100X for corresponding variation in alloy-silicon from 0.005 to 5.0 percent. This indicates that molybdenum by itself does not effectively develop significant corrosion resistance to attack by halide-containing acids in these alloys. The silicon-deficient alloys also are characterized by a marked acceleration of attack after approximately 50 hours of immersion. This acceleration is attributed to the accumulation of unprotective corrosion products on the surface and is associated with an increase in the intensity of pit growth. The absence of this effect for the alloys containing at least 2 percent silicon is indicated by the linear rates observed for alloys XA-16 and XA-15.

It should be noted that these observations have been discussed with specific reference to pitting corrosion of austenitic stainless steels. These specific conditions were chosen for discussion by way of example. The hypothesis on which this approach to corrosion behavior is based, however, it not necessarily limited to a single type of corrosion nor to one

class of alloys. There is increasing evidence that surface studies of this type can provide an effective approach toward clarifying understanding of corrosion behavior over a broad range of corrosion conditions and alloy compositions.

5. Summary

The main principles of this discussion of the behavior of thin films may be generalized as follows:

1. Thin films on metal surfaces have unique compositional and structural properties. Consideration of these properties provides a practical basis for the interpretation of surface phenomena.
2. Film properties are particularly sensitive to alloy composition, corrosion medium, and surface treatment. They reflect the intrinsic capacity of a metal surface to protect itself against corrosion.
3. The colloidal behavior of heteropoly acids associated with the protective nature of films isolated from surfaces of stainless alloys may have a general significance in the interpretation of film properties and corrosion behavior.
4. Certain alloying elements such as silicon and molybdenum are strong film modifiers, and tend to interact to form films associated with superior alloy corrosion resistance.

6. Acknowledgments

The writer is indebted to his colleagues at the Engineering Research Laboratory, particularly N. A. Nielsen, for the data used in Figures 1 and 2. He is also grateful to H. W. McGonigal, L. E. Haley, and R. H. Fisher for their assistance in the experimental work here reported.

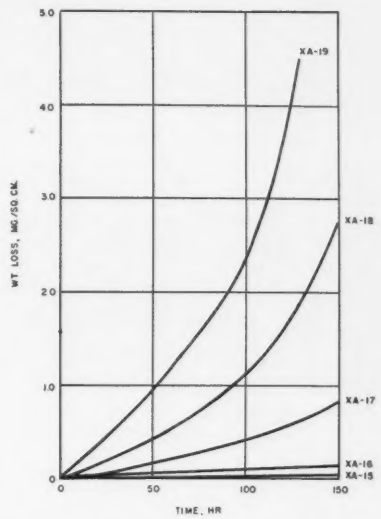

Figure 15—Corrosion rates of experimental silicon-modified Type 316L stainless steel in 10 percent $FeBr_3$ at 25 C. Samples pretreated in 5.0 percent HNO_3-0.5 percent $K_2Cr_2O_7$ at 60 C for 30 minutes.

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Any discussion of this article not published above will appear in the December, 1956 issue.

PREVENTIVE MEASURES, CA

Partial protection is also very desirable in many cases involving poorly coated lines and can be justified by reductions in sinking fund deposit factors due to increased pipe life, in addition to usual savings in operations.

Electrical engineers should anticipate that cathodic protection will effect savings in other corrosion areas. Power plant equipment, cables, substations, docks, ships and other situations involving metals in contact with soils and solutions are fertile fields for the application of cathodic protection and modern techniques of corrosion control

5.2.1-56 CORROSION CONTROL OF STEEL EQUIPMENT. T. R. B. Watson. **Can. Chem. Processing, 37,** No. 10, 46, 48, 50, 52, 54 (1953) Sept.

Describes causes of corrosion and discusses control by means of cathodic protection.

5.2.1-57 CATHODIC PROTECTION LICKS CORROSION. L. C. Werkin. **Petroleum Refiner, 31,** No. 9, 122-124 (1952) Oct.

Cathodic protection, a positive, controllable and inexpensive method of preventing corrosion. There is real money in reducing these losses caused by corrosion-maintenance, replacement costs, over-design of equipment, and product losses. Refinery management and technical personnel must be keenly aware of the creeping inroads of corrosion, and alert to any feasible solution to the problem. Table showing cost estimates and savings resulting from its use on a large open-box-type refinery condenser and a large diameter Dorr clarifier. 9 refs.

...THODIC PROTECTION OF STEEL. F. ...Nurse, H. C. K. Ison and T. W. Farrer. ...ry, No. 40, 972-974 (1952) Oct. 4.

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5.2.2 PREVENTIVE ... PROTECTION, AN...

a. General ...
b. Magnesium ...

5.2.2-1 CATHODIC PRO... ANODES. Brochure, June, 1953 ...tute, 60 East 42nd Street, New ...

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A Contribution to the Work of NACE Technical Committee T-3H On Tanker Corrosion

Some Considerations in the Economics of Tanker Corrosion*

By C. P. DILLON*

Abstract

A concept is presented whereby the capitalized cost of deferred repairs is considered when economic justification of corrosion control measures on oil tankers is contemplated. The author suggests a means whereby data pertaining to tankers can be used in establishing justification for or causing abandonment of corrosion control schemes.

When capitalized cost is considered, the savings attributable to corrosion mitigation measures are much less than when calculated without taking into account earned interest on accumulated **repair funds.** Formulae are presented and a suggested graphical presentation of the data is included.

Introduction

IF CERTAIN DATA pertaining to the cost, age to obsolescence, cost of repairs and others can be determined with respect to oil tankers, at least two methods can be used to determine whether or not corrosion control measures are economical. Complex economical considerations must be weighed in any problem associated with corrosion control on any large and expensive structure.

Data and figures included in this article are illustrative only. It is hoped the concept outlined will arouse sufficient interest among persons concerned with the subject to stimuate further study and especially to establish the basic economic prerequisites mentioned.

Capitalized Costs

If it is assumed a tanker ship costs $6,000,000 and has a life of 24 years after interim repairs, potential corrosion control savings arise from minimizing or eliminating repairs. For instance, assume repairs at 12 years will cost $1,000,000 and subsequent repair bills at 16 and 20 years will be $500,000 each. The first approximation of annual costs is then $2,000,000, which divided by 24 years gives an average of $83,500 per year.

This thinking ignores the fact that money, while being accumulated for future repairs, can be earning interest. This fact can be taken into consideration by using the concept of "Capitalized costs."[1]

"Capitalized Cost" essentially is a means of amortizing the cost of an infinite number of replacements. For example, it is desired to purchase a new $3500 automobile every four years. Five percent interest on capital is available. The capitalized cost of the automobile is $20,000—that is, a new automobile is purchased for $3500 and 16,500 is invested at 5 percent the same year. Four years later the investment will return the $3500 needed for the new model and leave the $16,500 principal invested. This arrangement may be continued indefinitely.

Capitalized Costs of Tanker Corrosion

Capitalized cost is defined by the expression:

$$(K-C)\ (1+i)^m = K \text{ or } K = \frac{C\ (1+i)^m}{(1+i)^m - 1} \text{ or } K = CF_m \qquad (1$$

Where:

K is the Capitalized Cost
C is the initial cost
i is the interest rate (expressed as a decimal)
m is the life of the article in years
F_m is the factor value equivalent to the interest calculation

The capitalized cost of a single deferred cost is:

$$K = HF_m\ (1+i)^p \text{ where} \qquad (2$$

H is the cost of the deferred expense
p is the number of years during which the expense is incurred

From Equation (2, the maintenance costs postulated are

$1,000,000 at 12 year—	$354,500	
500,000 at 16 year—	212,000	
500,000 at 20 year—	82,500	
	$694,000	total capitalized cost of repair

The capitalized cost of the tanker is the total of all capitalized costs, e.g., initial investment, annual repairs, annual maintenance costs, etc. The total cost for purposes of this discussion is, if a deferred repair "R", and no treatment is contemplated

$$K = CF_m + RF_m/(1+i)^p \qquad (3$$

and for a $6,000,000 ship this is:

$$K = \$6{,}000{,}000\ (1.113) + 649{,}000 = \$7{,}327{,}000$$

If a counter-corrosion treatment "T" is introduced, it can be considered as an article having a life of one year and the total cost "K" will be:

$$K = CF_m + TF_1 + RF_m/(1+i)^p \qquad (4$$

★Presented at a meeting of Unit Committee T-3H at New York, N. Y., March 14, 1956.

*Carbide and Carbon Chemicals Co., Texas City, Texas.

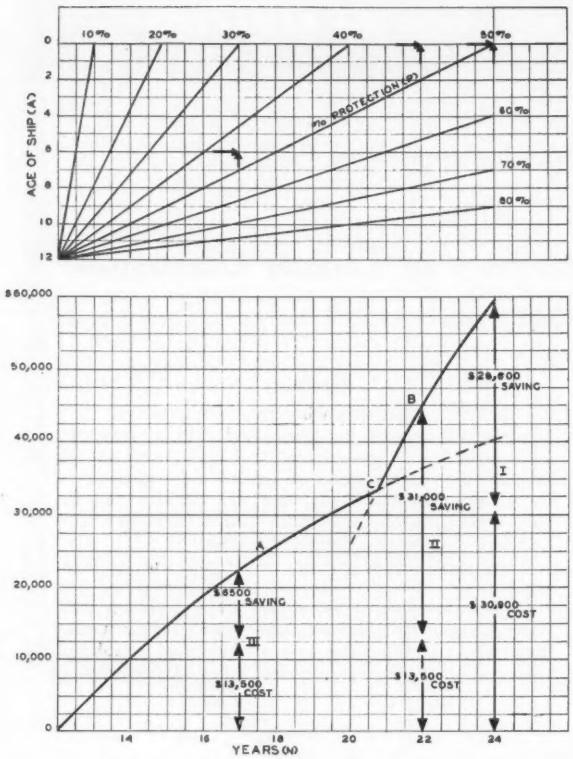


Figure 1—Showing the method of computing real savings of corrosion control measures while considering capitalized cost of deferred repairs.

Obviously, the capitalized cost by Equation 4 must not exceed that from Equation 3 if the counter-corrosion treatment is to be economical. The saving effected here includes consideration of the interest accumulated by delaying repair. The maximum allowable counter-corrosion expenditure "T" at various values for p can be solved for by Equating 3 and 4. (This considers the repair measures as equivalent to a single major repair at 12 years). Curve A in Figure 1 is drawn from the following data:

p	T
12	0
14	10,600
16	18,800
18	25,800
20	31,600
22	36,400
24	40,300

The largest savings are effected when the repairs are eliminated and the ship reaches obsolescence solely through the counter-corrosion measures. For this special case:

$$K = CF_m + TF_1 \qquad (5$$

Now, T, the maximum allowable annual expenditure for counter-treatment for various values of m in Equation 5 can be solved by equating 3 and 5 to get Curve B in Figure 1 as follows:

m	T
18	12,700
20	25,800
22	44,400
24	59,500

The point C, where Curves A and B intersect is the point at which, if reached without major repairs, it is as economical to declare the ship obsolete as it is to make major repairs to attain 24 years' life.

Therefore, any life attained at less than C years requires repair, while and greater life effects tremendously greater savings and should be pushed to its maximum useful limit so long as major repairs are not required.

Thus far, everything has been expressed in years to time of repair or obsolescence. Introducing the concept of percent protection against corrosion, it can be observed that a ship several years old takes a higher percent protection to reach any given number of years than does a new ship. For these stipulations, i.e., major repairs starting not sooner than 12 years, the percent protection needed to reach N years before repairs is expressed as follows:

$$N = (12A)/(1 - P) + A \qquad (6$$

Where:

A is the age of the ship when treatment is begun and
P is the percent protection expressed as a decimal.

By solving for various protection figures from various stages in the life of a ship, the upper part of the graph is derived and the chart's usefulness extended to ships of various ages, granting the basic assumptions.

Use of Graph in Figure 1

Using the concept of capitalized cost, the maximum possible gross annual savings to the time at which necessary repairs are effected and to the time in the life of a ship when it is more economical to declare it obsolete than to repair it has been related. This in turn has been related to the percent corrosion protection needed to achieve such results for ships of different ages when the counter corrosion treatments are begun.

Curve A represents the savings effected by delaying repair and these savings consist essentially of the money earned by the maintenance repair fund during the delay effected. Curve B represents the savings by eliminating the need for repair. The maximum possible saving in our example is $59,500 rather than $83,500 as first approximated. The point C at which the two curves intersect is that age of the ship at which, having been achieved without major repairs, it is as economical to declare the ship obsolete as it would be to make major repairs to reach a life of 24 years. The line A-B-C now represents the maximum amount of money that can be spent under any particular combination of ship age, percent protection and ship life. If the cost of treatment falls on or above line A-B-C, then the treatment is uneconomical and normal corrosion and repair is the better choice.

Examples:

1. For a new ship it is estimated that the annual cost

of installing and maintaining an internal paint application is $30,900. This will give complete protection and effect the maximum gross savings. Net annual savings are then $59,500 minus $30,900 or $28,600. See Example I, Figure 1. On the other hand, if a cathodic protection installation costs $13,500 annually and gives only 45 percent protection, it will still give 22 years life. The net annual saving is then $31,000, which is preferable to painting as a counter measure even though the ship is declared obsolete at an earlier age. See Example II.

2. Suppose the ship was already six years old when the corrosion problem was recognized. Now, a paint application will give the same annual savings of $28,600 as in Example I. On the other hand, 45 percent protection from an anode installation will only give a life, to the time of repair, of 17 years. Now the gross annual saving for the latter measure is only $22,000 and the net saving $6500. See Example III. In this case the coating approach is the most economical choice.

Conclusions

The chart as prepared suffers certain defects, among them the problems of taxes and depreciation, which might require the Venture Worth[2] approach for resolution. In order to make this type of graph accurate and useful, some of the basic values must be determined. For example, the committee could survey the field and get firm data on some of the following points:

1. At what age does a tanker become obsolete?
2. What is the salvage value?
3. What is the cost of a new tanker?
4. What is the cost of repairs and when do they take place?
5. What are the true costs of the various countercorrosion measures?
6. What percent protection do the various countercorrosion measures give in practice?

If these questions could be answered, the economic justification of any given treatment of any tank ship could be determined readily and easily.

References

1. Next Time Use Capitalized Costs. By F. C. Jelen. *Chem. Eng.*, (1954) Feb.
2. The Venture Worth Method for Economic Balances. By J. Hoppel. *Chem. Eng. Prog.*, (1955) Dec.

Three T-7 Coordinating Committees to Be Set Up At NACE Regional Sessions This Fall

Group Committee T-7, Corrosion Coordinating Committee will initiate formal organization at three NACE regional meetings this fall. Meetings are planned at the North Central Region meeting, November 15 at the Hotel Statler in Detroit, Michigan; Northeast Region meeting, October 15, at the Drake Hotel in Philadelphia and at the South Central Region meeting, October 24 at The Gunter Hotel in San Antonio, Texas.

Jack M. Fouts, New York Telephone Company, Buffalo, New York and C. A. Erickson, Jr., The Peoples Natural Gas Company, Pittsburgh, Pennsylvania, chairman and vice chairman respectively of T-7 have held several conferences planning programs for the fall meetings.

Programs planned are as follows:

Northeast Region Meeting—The T-7 meeting will convene at 2 pm. There will be a brief history of T-7 and philosophy of interference coordination presented by Mr. Fouts. Following this the chairman and vice-chairman will explain the proposed organizational plans for regional units. Stressive lines of communication and exchange of information. Immediately following the T-7 meeting the Northeast Region Unit Committee T-7A will hold its organizational meeting. Mr. Erickson is chairman of the T-7A committee and Andrew Kellogg, Niagara Mohawk Power Corporation, Syracuse, New York is vice-chairman.

South Central Region Meeting—The T-7 meeting will convene at 2 pm. The same general plan as at the Northeast Region meeting will be followed. Plans for a South Central Region unit committee of T-7 will be discussed in detail and following the T-7 meeting an organizational meeting of the unit will be held.

North Central Region Meeting—The T-7 meeting will convene at 2 pm. This meeting is being held for the express purpose of discussing the objectives of T-7 with those interested. It is hoped a chairman and vice-chairman for the proposed North Central Region unit committee of T-7 can be selected at the meeting and plans laid for the unit committee organization.

Group Committee T-7 was formally organized and officers selected at the 1956 NACE New York conference. Its objective is to provide coordination among the so-called electrolysis or corrosion coordinating committees organized among operators of underground metallic plant. Its scope is as follows: This committee is interested in promoting cooperation and providing a medium for the exchange of information between the various groups known as Electrolysis or Corrosion Coordinating Committees on the North American continent. The scope of this committee is limited to liaison functions and providing a medium for the exchange of information between coordinating committees.

It will not engage in technical study projects as such but may participate cooperatively with established technical units in the study of technical matters pertinent to coordination problems. It is the function of this committee to collect and compile information concerning the by-laws or operating rules of the various existing coordinating committees and make this information available to other committee groups interested in forming coordinating committees in areas where none exist. It is also the function of this committee to collect and compile information concerning notification procedures, location of metallic underground plant, corrosion protection systems operated on the underground plant and personnel responsible for corrosion work on underground structures in each locality.

All information compiled by this committee will be made available for exchange within the various units as may be required to assist the members in maintaining cooperation and coordination between the committees in the various localities. The committee will study the information obtained and make recommendations for simplification and uniformity in coordinating procedures when deemed advisable by the members.

As a long range project it is the objective of this committee to condense and consolidate pertinent information into a directory or handbook that will require a minimum of effort to keep up to date. The scope of all unit committees under this group shall be identical with group committee scope with the functions of each unit committee confined to its own region.

Six Committees Have Scheduled Sessions at Philadelphia Meeting

Six committees have scheduled meetings during the NACE Northeast Regional Meeting to be held in the Drake Hotel, Philadelphia, Pennsylvania, October 15-17. All committee meetings will be held on October 15. Committees meeting are:

T-2K, Prefabricated Plastic Film for Pipe Line Coating

T-4F, Materials Selection for Corrosion Mitigation in the Utility Industry

T-4F-1, Materials Selection in the Water Industry

T-4F-2, Materials Selection in the Electric Industry

T-7, Corrosion Coordinating Committee

T-7A, Corrosion Coordinating Committee, Northeast Region.

All committee meetings will be open to guests. T-2K committee plans to hold discussions on task group activities which include work on history and results of use of plastic film, physical characteristics, research and development, application and standards. T-2K will hold a similar meeting in San Antonio the week following at the South Central Region meeting. T-4F and the two task groups, T-4F-1 and T-4F-2, will discuss progress made since their reorganization in New York during the conference. T-7 and T-7A are primarily organizational meetings. Anyone interested in underground corrosion and the coordinating necessary is urged to attend the meeting.

Report Completed on Acid Proof Masonry Vessel Construction

A report on "Acidproof Vessel Construction with Membrane and Brick Linings" has been completed by NACE Technical Unit Committee T-6K on Corrosion Resistant Construction with Masonry and Allied Materials.

T-6K was organized for the purpose of collecting and disseminating up-to-date information on the use of masonry and allied materials for chemical resistant vessels, stacks, floors and related equipment. The completed report is the first of several that will be developed by the committee.

Descriptions of materials and discussions on usefulness in the report are limited to facts intended to provide basic information and understanding of selection and use. The committee recognizes that there are materials available other than those covered which will give good service. These, however, are used infrequently in American industry and are outside the scope of the report. The report is divided into four main sections: Vessels, membrane linings, cements, masonry linings. Major attention is given to cements and masonry shapes.

Phenol Cements Developed

The history of the development of chemical resistant masonry construction for tanks and related equipment is covered briefly. Circumstances during World War I demanding better equipment to handle more corrosive materials instigated work on this type of construction. Initially attempts were made to obtain protection by using tars and asphalts, but they proved generally unsatisfactory because of poor chemical resistance and poor resistance to thermal and mechanical changes. In 1930 the first of the chemically setting resin cements was developed. It was based on phenol formaldehyde and a silicate filler. A major improvement in mechanical properties and suitability for overall use was made in 1934 when a means of plasticizing sulfur and a siliceous aggregate was developed. Steady improvements have been made since.

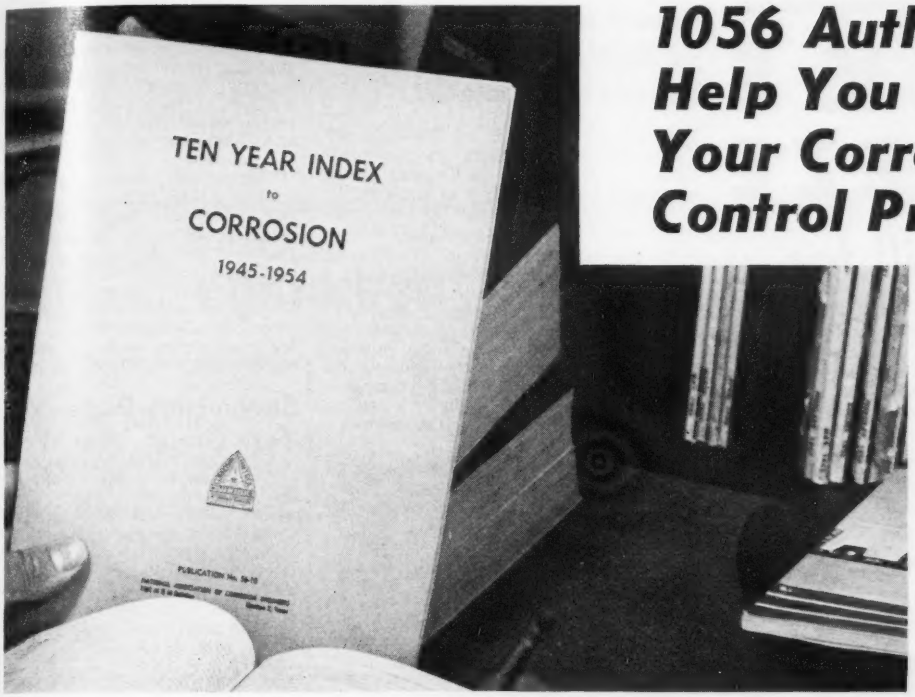
Two sections of the report are devoted to construction of steel and concrete vessels.

A third section is devoted to membrane linings that are always desirable for use between a vessel shell and acid-proof brick. This lining is necessary to protect the vessel shell from chemical attack by the solution which gets through pores or cracks in the brick lining. Materials most widely employed for this purpose are sheet elastomers and plastics. Serviceability of and gen-3/32-inch to 1/4-inch. These are bonded continuously to the steel or concrete vessel shell by cementing. Asphaltic materials frequently are used on concrete vessels. Sheet lead has been employed extensively in the past, but its use is decreasing in favor of the elastomers and plastics. Serviceability of and general preference for membrane materials for specific media are tabulated in the report.

Major Cements Described

A section of the report is devoted to chemical resistant cements designed pri-

(Continued on Page 74)



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Report on Linings Used To Reinforce Brick Vessels Is Completed

A technical report on "Reinforced Tank Linings" has been completed by Task Group T-6A-14 on Organic Brick Covered Linings of Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion.

In the report the term "reinforced tank linings" refers to resins or plastics used in conjunction with brick or tile or with a fabric reinforcing. The materials generally consist of a solvent-free liquid resin with an inert powder filler mixed to a stiff mortar consistency which hardens at ordinary temperatures as the result of action by a setting agent added with the powder filler.

Almost any synhtetic resin in liquid form or which can be dissolved in a common solvent is a basis for a corrosion resistant cement mortar. Application depends upon factors such as attainable physical properties, chemical resistance and adaptability for easy handling. These factors reduce the number of materials for general use to a few.

The report covers in detail the most widely used cements including furan resins, phenolic resins, polyester resins and epoxy resins. Methods of preparation and advantages of each are given, typical physical and mechanical properties outlined and comprehensive tables listing resistance in the following media are included: Acids, alkalies, gases, oils, oxidizing agents, salts, solvents. Resistance tables specify generally recommended, limited recommendation and not generally recommended.

Special materials can be produced to conform to special requirements involving such considerations as appearance, color, food laws, adhesion to particular surfaces, extreme flexibility or rigidity and insulation in addition to chemical resistance.

The report mentions and briefly describes other important corrosion resistant cements produced from natural products or from inorganic materials. Included are: Asphaltic and bituminous materials, sulfur and silicate cements.

The report is currently under review by members of Unit Committee T-6A. When finally approved by the committee the report will be submitted for publication in CORROSION.

Seven High Purity Water Task Groups Are Working

Activities of Unit Committee T-3F on High Purity Water are divided among seven task groups.

Task group assignments and their chairmen are: 1. Facilities for the Production of High Purity Water, F. N. Alquist, The Dow Chemical Co., Midland, Mich., chairman; 2. Inhibitors, R. C. Ulmer, Combustion Engineering, Inc., New York, N. Y., chairman; 3. Corrosion Products, R. U. Blaser, Babcock and Wilcox Co., Alliance, Ohio, chairman; 4. General Corrosion Problems, V. J. Payton, Commonwealth Edison Co., Chicago, Ill., chairman; 5. Declassification and Bibliography, A. H. Roebuck, Continental Oil Co., Ponca City, Okla., chairman; 6. Intercommittee Activities, F. N. Alquist, The Dow Chemical Co., Midland, Mich., chairman.

T-3F has sponsored a symposium at the past two NACE Annual Conferences and is planning another for the 1957 Conference in St. Louis.

Active Local Committee's Work Proves Helpful to Petroleum Producers

Unit Committee T-1A on Corrosion of Oil and Gas Well Equipment (Los Angeles Area) is a good example of the advantages of organizing a local technical committee. Some sixty representatives of oil companies in the Los Angeles area participate in its activities. Monthly meetings are held at which various phases of corrosion of oil and gas well equipment are discussed, and guest speakers often are invited to present papers.

Subjects discussed and papers presented at meetings held during 1956 include: A paper on "Automatic Batch Injection of Corrosion and Scale Inhibitors;" round table discussion on relative merits of batch and continuous injection, optimum frequence of treatment; discussion of marine testing of protective coatings; paper on "Cathodic Protection of Oil Well Casings at Kettlemen Hills;" a paper covering the Long Beach Harbor Water Flood Project.

The committee reports its activities in detail to Group Committee T-1 twice annually at meetings of the parent committee.

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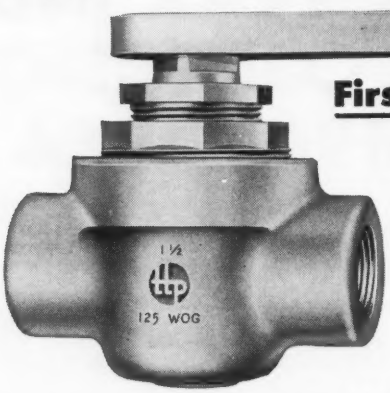

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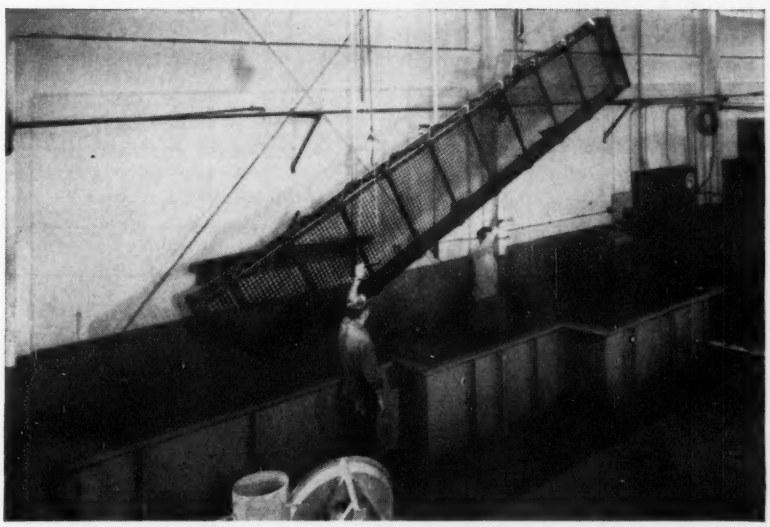

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SOUTH CENTRAL REGION TECHNICAL PROGRAM MEETINGS

Gunter Hotel, San Antonio, Texas Oct. 23-26, 1956

Tuesday, Oct. 23

AM	T-1 9-11:30						
PM	T-1 1:30-5	T-2E 1:30-4:30	T-6B 1:30-4:30	T-2K 1:30-4:30	T-3G 2:00-4:30	T-5D 2:00-5:00	T-2B 2:00-5:00

Wednesday, Oct. 24

AM	T-1K 8:30-11:30	T-2J 9:00-11:30 T-5B-3 9:00-11:30	T-6E 8:30-11:30	T-5C-1 8:30-11:30	T-2C 8:30-11:30	T-1H 8:30-11:30	T-6A 8:30-11:30
PM	T-1G 2:00-3:30 T-1F 3:30-5:00	T-2D 2:00-4:30	T-5E 2:00-4:30	T-6D 2:00-4:30	Naphthenic Acid Corrosion Comm. 2:00-4:30	T-7 2:00-4:30	T-1M 2:00-4:30

Thursday, Oct. 25

AM			T-1D 9:00-11:30	T-1J 9:00-11:30	Author's Breakfast 7:30-8:30	Pipe Line Industry Symposium 8:30-11:30	Elevated & High Temperature Symposium 8:30-11:30
PM				T-5B-2 2:00-5:00		Oil & Gas Production Symposium 2:00-5:00	Utilities Industry Symposium 2:00-5:00

Friday, Oct. 26

AM			T-1B 9:00-11:30	T-5B-2 8:30-11:30	Author's Breakfast 7:30-8:30	Cathodic Protection Symposium 8:30-11:30	Transportation Industry Symposium 8:30-11:30

Some Topics on Agendas of 27 Technical Committees to Meet at San Antonio

Twenty-seven technical committees are scheduled to hold meetings at San Antonio, Texas, during the South Central Region Meeting, October 23-26. All meetings will be in the Gunter Hotel.

Committees meeting and subjects for discussion are as follows:

T-1 Corrosion of Oil And Gas Well Equipment. Scheduled to meet all day Tuesday, October 23. T-1 will hear progress reports from all ten T-1 unit committees.

A portion of the meeting will be devoted to discussion of the Manual on Corrosion of Oil and Gas Well Equipment prepared by an editorial committee of T-1. The manual was written for the purpose of introducing personnel to the problems of oil and gas well corrosion. It is written in nontechnical and semitechnical language so it will be useful to field foremen, field engineers and beginning corrosion engineers at the request of the American Petroleum Institute Committee on Vocational Training. A joint meeting of the NACE T-1 Editorial Committee and an API Review Committee will be held in August to consider final changes to be made before the book is published.

Much of the meeting will be devoted to a roundtable discussion of corrosion of oil and gas well equipment and new developments in preventive measures.

T-1B Condensate Well Corrosion. Scheduled to meet at 9 am Friday, October 26. The entire committee is acting as a task group to study controlling corrosion in wells where the pressures are in excess of about 5000 psi. The committee will discuss service life and protection of tubing strings of all types in extreme high pressure wells, sour condensate wells and on high pressure, high gas/oil ratio wells.

T-1D Sweet Oil Well Corrosion. Scheduled to meet at 9:00 am Thursday, Oc-

(Continued on Page 75)

Report Is Completed–

(Continued from Page 70)

marily for joining acidproof shapes where exposure to corrosive acids, alkalies, salts, or solvents is involved. Described in detail are furan, phenolic, sulfur and silicate cements. The resistance of these cements to specific chemicals and their important physical properties are given in tables.

Cost data for component parts of membrane and brick lined vessels of moderate size are given.

The balance of the report is devoted to masonry linings. Chemical resistant bricks are used with membranes in tanks to reduce the temperature at the membrane to a safe maximum, to prevent mechanical damage to the liner and to permit use of a membrane that otherwise would deteriorate from attack by the chemicals.

Some Topics—

(Continued from Page 74)

tober 25. T-1D will hear progress reports from task groups in the West Texas-New Mexico and Western Kansas areas. Service performance of coatings will be discussed. Inhibitors will be discussed.

T-1F Metallurgy. Scheduled to meet at 3:30 p.m. on Wednesday, October 24. T-1F will discuss sucker rod string test and high strength tubing data being gathered by members of the committee.

T-1G Sulfide Stress Corrosion Cracking. Scheduled to meet at 2 pm on Wedneday, October 24. T-1G will discuss progress on task group assignment to develop a standardized test for testing materials' resistance to stress corrosion cracking and also will hold further discussion on results of research project recently completed at Yale University on sulfide stress corrosion cracking.

T-1H Oil String Casing Corrosion. Scheduled to meet at 9 am on Wednesday, October 24. T-1H will hear progress reports from task groups in the West Texas, Kansas, East Texas and West Coast areas. Discussion will be on cathodic protection of oil string casing.

(Continued on Page 76)

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Some Topics—

(Continued from Page 75)

T-1J Oil Field Structural Plastics. Scheduled to meet at 9:00 am on Thursday, October 25. T-1J will hear service and manufacturers' reports on plastic tubing and tanks. A questionnaire on use of extruded plastic pipe for oil field service has been distributed by T-1J. Questionnaire replies received will be discussed.

T-1K Inhibitors for Use in Oil and Gas Wells. Scheduled to meet at 8:30 am on Wednesday, October 24. T-1K will discuss new projects for the committee. Results of continuing testing of the T-1K procedure for screening inhibitors will be surveyed.

T-1M Corrosion of Oil and Gas Well Producing Equipment in Offshore Installations. Scheduled to meet at 2 pm on Wednesday, October 24. T-1M will discuss progress reports from task groups on protective barriers, cathodic protection and structural design.

T-2B Anodes for Impressed Currents. Scheduled to meet at 2 pm on Tuesday, October 23. T-2B will discuss subjects under study by task groups of the committee including sources of impressed current for anodes, ground bed design, use of high silicon cast iron for anodes and use of platinum, palladium, etc. for anodes.

T-2C Minimum Current Requirements. Scheduled to meet at 8:30 am on Wednesday, October 24. Main topic for discussion will be T-2C work on minimum current criteria for cathodic protection of buried pipe lines.

T-2D Standardization of Procedures for Measuring Pipe Coating Conductance. Scheduled to meet at 2 pm Wednesday, October 24. T-2D will discuss progress of task groups assigned to develop methods of measuring pipe coating conductance under special circumstances including short insulated sections of low conductance, inaccessible locations such as water crossings, parallel lines, pipe lines where marked polarization interferes with measurements and pipe that is observed to be in a stray current field.

T-2E Internal Corrosion of Product Pipe Lines and Tanks. Scheduled to meet at 1:30 pm on Tuesday, October 23. T-2E will discuss progress on the committee sponsored corrosion coupon tests in product pipe lines.

T-2J Wrappers for Underground Pipeline Coating. Scheduled to meet at 9 am Wednesday, October 24. T-2J will discuss progress of task groups' working on minimum standards for various pipe wrapping materials and tests for materials.

T-2K Prefabricated Plastic Film for Pipe Line Coating. Scheduled to meet at 1:30 pm on Tuesday, October 23. T-2K will discuss progress of task groups on history and results, physical characteristics, research and development, application and standards.

T-3G Cathodic Protection. Scheduled to meet at 2 pm on Tuesday, October 23. T-3G will hear activity reports from task groups on cathodic protection of ship hull bottoms, heat exchangers and process equipment. A discussion on general cathodic protection problems also will be held.

T-5B-2 Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry. T-5B-2 will hold two half-day meetings, one at 2 pm on Thursday, October 25 and one at 8:30 am on Friday, October 26. One meeting will be devoted to discussion of two papers on the subject under study by the committee scheduled to be presented at the Elevated Temperature Symposium Thursday morning. The second half day meetings will be devoted to discussion of data to be presented by members of the committee.

T-5B-3 Oil Ash Corrosion. Scheduled to meet at 8:30 am on Wednesday, October 24. This will be the first meeting of the Task group and will be devoted to organization.

T-5C-1 Corrosion by Cooling Waters (South Central Region). Scheduled to meet at 8:30 am on Wednesday, October 24. T-5C-1 will discuss progress reported by study committees on recirculating cooling water, once through cooling water, inhibitors and stress corrosion cracking. The committee is currently conducting sponsored test in several committee-member plants on stress corrosion cracking of stainless steel in cooling waters.

T-5D Plastic Materials of Construction. Scheduled to meet at 2 pm on Tuesday, October 23. T-5D will discuss activities of its eight task groups. Portions of meeting will be devoted to general discussion of current use of plastics as materials of construction in the process industries.

T-5E Stress Corrosion Cracking of Austenitic Stainless Steel. Scheduled to meet at 2 pm on Wednesday, October 24. T-5E will discuss joint questionnaires on stress corrosion cracking of stainless steels undertaken by T-5E and Sub-committee IV of ASTM Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys.

T-6A Organic Coatings and Linings for Resistance to Chemical Corrosion. Scheduled to meet at 8:30 am on Wednesday, October 24. T-6A will discuss a report on organic-brick linings prepared by task group T-6A-14. Progress of other task groups will be surveyed.

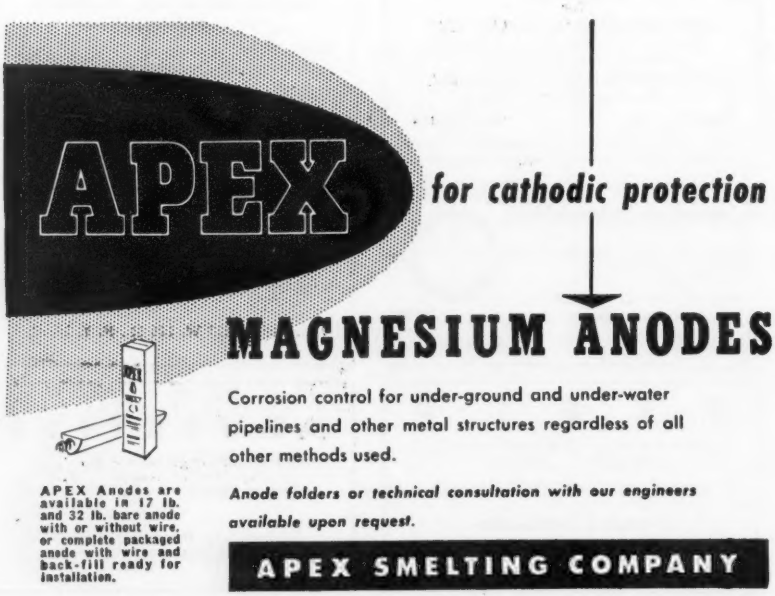
T-6B Protective Coatings for Resistance to Atmospheric Corrosion. Scheduled to meet at 1:30 pm on Tuesday, October 23. T-6B has completed the initial phase of its work. A report on Protective Coatings for Atmospheric Use has been completed and is being considered for publication. The committee now plans to go into more detailed study of coatings for use in atmospheric environments. Future work will be discussed.

T-6D Industrial Maintenance Painting. Scheduled to meet at 2 pm on Wednesday, October 24. This new NACE technical committee is meeting to organize and outline its activities. The scope of the committee is to discuss, study, report and publish information relative to industrial maintenance painting and to advance the cause of corrosion engineering by informing process industry management and supervisory personnel of the advantages to be gained by sound corrosion control and preventive measures. Emphasis will be placed on protective coatings applications and painting programs.

T-6E Protective Coatings in Petroleum Production. Scheduled to meet at 8:30 am on Wednesday, October 24. T-6E is being reorganized and the meeting will be devoted to assignment of task groups to study various aspects of protective coatings used in petroleum production.

T-7 Corrosion Coordinating Committee. Scheduled to meet at 2 pm on Wednesday, October 24. The meeting will be devoted to a discussion of the reasons for organizing Group Committee T-7 and plans for achieving aims outlined in the committee's objectives. It is tentatively planned to hold an organizational meeting of a South Central Region unit committee of T-7 following the T-7 meeting.

Naphthenic Acid Corrosion Committee. Scheduled to meet at 2 pm on Wednesday, October 24. This proposed new NACE technical group is to talk about naphthenic acid corrosion problems and to take preliminary steps to organize.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Tentative Program Is Outlined for Shreveport Course

A tentative program for the Sixth Annual Corrosion Control Short Course, sponsored by Shreveport Section NACE with cooperation of Centenary College has been completed. Courses will be conducted September 20-21 in the air conditioned Science Building at the college.

The program is Registration, Introduction of guests; Welcoming remarks, W. F. Fair, Jr., Koppers Co., Inc., Pittsburgh, NACE president.

Fundamental Causes of Corrosion, M. C. Miller, Allendale, N. J.; Cathodic Protection Survey Design, Wayne Johnson Corrosion Rectifying Co., Houston; Cathodic Protection Maintenance, Robert L. Bullock, Interstate Oil Pipe Line Co., Shreveport.

Other topics scheduled during the course are acthodic protection instruments, corrosion control in processing plants, oil and gas well corrosion control, well casing cathodic protection, atmospheric corrosion control, plastic materials for corrosion control, corrosion control in distribution systems and underground protective coatings.

Persons scheduled to participate in the technical program include M. J. Olive, Arkansas Fuel Oil Co., Shreveport; Frank Dorr, Brance-Krachy Co., Houston; Warren McKenny, Mavor-Kelly Co., Houston; Joseph Rench, Napko Co., Houston and George Holm, Tube Kote Co., Houston.

A field trip will be held beginning at 1:45 pm September 21 at which a demonstartion of inhibitor treatment of oil and gas wells will be presented, including analysis of coupon tests and water samples. A cathodic rectifier installation on a pipe line system also will be inspected.

The annual fellowship hour and banquet will be held beginning at 7 pm at the Physicians' and Surgeons' hotel.

Course registration fee is $10, covering two noon meals, the banquet and fellowship hour.

Conference officials are: Lionel Morrow, Interstate Oil Pipe Line Co., general chairman; John Wise, Arkansas-Louisiana Gas Co. and Ed Sullvian, United Gas Pipe Line Co. are chairman and co-chairman of the program committee respectively. Mike Deodati, United Gas Pipe Line Co. and Ned Stearns, D. E. Stearns Co., are co-chairmen of the banquet and entertainment committee. Justin Griffin, Texas Eastern Transmission Co. is in charge of local arrangements with Frank Rickham, Irish Engineering Co. as co-chairman.

Bob Naremore, Arkansas Fuel Oil Corp. and Jim Butler, Arkansas Louisiana Gas Co. are in charge of mail and publicity.

HALF-YEAR MEMBERSHIPS AVAILABLE

Active membership in the National Association of Corrosion Engineers for the six months July-December, 1957 inclusive is available at $6. Membership includes copies of CORROSION and all other privileges. Applications may be obtained on request from A. B. Campbell, Executive Secretary, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.

Five Meetings of Regions, Three Short Courses Set

A busy fall—perhaps the busiest in the 12-year history of the National Association of Corrosion Engineers—is scheduled this year. Programs have been announced for five regional meetings to take place in 30 days, between October 15 and November 16. In addition, during this same period a short course is tentatively scheduled on the West Coast to be given by University of California at Los Angeles with cooperation of Western Region NACE.

Two short courses are scheduled during September, the first by Ohio State University, September 10-14 (program on Page 92, July issue) and by Shreveport Section on September 20-21 (programs in this issue).

Also in addition to this several section meetings will be held in various parts of the country.

Notable about the regional meetings are the facts that an exhibition will be held at San Antonio during the South Central Region meeting for the first time at a regional NACE meeting and the North Central Region will hold the first meeting ever held by this subdivision of the association at Detroit November 15-16.

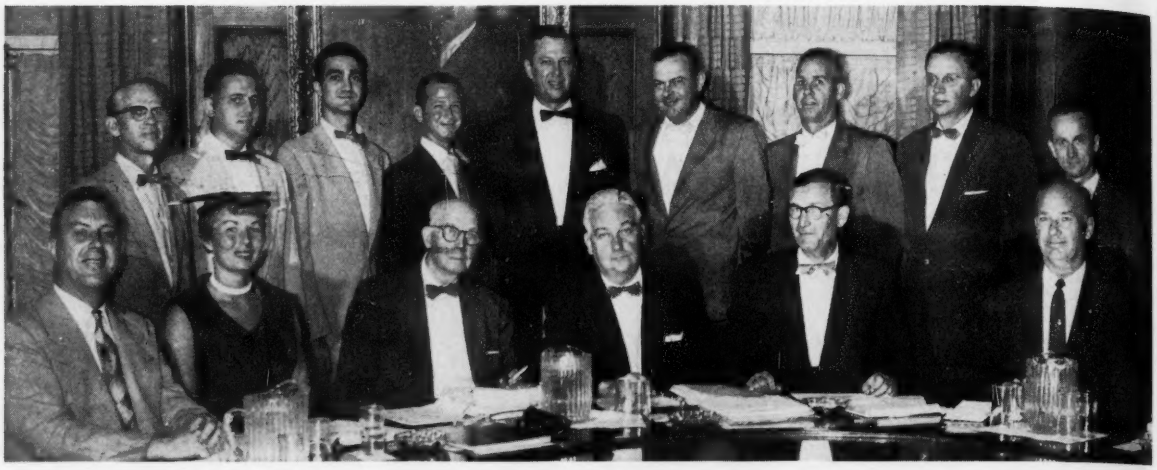
All Symposia Filled For Detroit Meeting

Symposia scheduled for the November 15-16 North Central Region meeting in Detroit are filled and plans are well under way for visits to plants of Wyandotte Chemical Corp., Chrysler Corp., International Salt Co. and Hiram Walker Distillery. Plans are being made for a banquet on the night of Thursday, November 15.

Members of Detroit Section working on the program indicate that the meeting will be both interesting and profitable. Because it is the first meeting of North Central Region, special pains are being taken to provide registrants' with a full schedule of activities, both business and social.

All sessions of the meeting will be held in the Detroit Statler Hotel, located across the street from Grand Circus Park and within a block of large downtown department stores, theaters and the airline terminal. Members planning to attend the meeting are urged to make hotel reservations as early as possible, directly with the hotel.

Technical sessions outlined for the meeting cover automotive, construction, chemical and utilities and power industries.



PARTICIPATING IN DISCUSSIONS of problems related to the 1957 NACE Conference and Exhibition in St. Louis at an NACE executive committee meeting on July 16 were, left to right, standing: E. L. Rice, National Lead Co., St. Louis, registration; William J. Ries, Tretolite Co., St. Louis, local arrangements chairman; R. D. Sanford, Nooter Corp., St. Louis, assistant local arrangements chairman; Charles G. Gribble, Jr., Metal Goods Corp., Houston and Walter B. Meyer, St. Louis Metallizing Co., exhibition co-chairmen; R. E. Effinger, Shell Oil Co., Houston, technical program chairman; Howard O. Nordquist, Jos. T. Ryerson & Sons, Inc., entertainment; R. H. Harper, Nooter Corp., publicity; seated: Otto H. Fenner, Monsanto Chemical Co., St. Louis, technical program co-chairman; Mrs. Mary Ellen Young, ladies' program; A. B. Campbell, NACE executive Secretary; W. F. Fair, Jr., Koppers Co., Inc., Pittsburgh, NACE president; W. H. Stewart, Sun Pipe Line Co., Beaumont, vice-president and R. A. Brannon, Humble Pipe Line Co., Houston, NACE treasurer.

NATIONAL, REGIONAL MEETINGS and SHORT COURSES

1956

Oct. 15-17—Northeast Regional Meeting, Philadelphia.

Oct. 23-26—South Central Region, Gunter Hotel, San Antonio, Texas.

Nov. 8-9—Southeast Region Fall Meeting, Charlotte, N. C.

Nov. 15-16—North Central Region Meeting, Detroit, Mich.

Nov. 15-16—Western Region. Long Beach, Cal.

1957

Mar. 11-15—NACE Annual Conference, Kiel Auditorium, St. Louis, Missouri.

May 20-22—Northeast Region Corrosion Control Conference, Syracuse University, Syracuse, N. Y.

1958

Mar. 17-21—NACE Annual Conference, Civic Auditorium, San Francisco, California.

1959

NACE Annual Conference, Sherman Hotel, Chicago, Illinois.

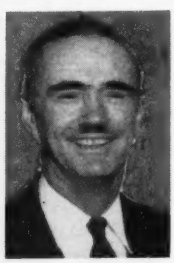
SHORT COURSES

1956

Sept. 10-14—Corrosion Short Course. Ohio State University, Columbus.

Sept. 20-21—Sixth Annual Corrosion Control Short Course. Shreveport Section. Centenary College, Shreveport, La.

Nov. 13-14—University of California at Los Angeles—Western Region (Tentative)



L. B. Donovan, Consolidated Edison Co. of New York (left) and J. E. Loeffler, Thornhill-Craver Co., Inc., Houston (right) have been named to fill two vacancies on the NACE Policy and Planning Committee by President W. F. Fair, Jr. The appointments extend to the last day of the 1959 NACE Conference.

Subjects for Five Montreal Dinner Meetings Given

Subjects for five dinner meetings of Montreal Section have been selected. First meeting on September 11 will be on industrial painting. Meetings, all on second Tuesdays monthly will be held at Queen's Hotel, Montreal on the following subjects: Corrosion control by inhibitors, chemical plant corrosion, corrosion in utility companies and oil refinery corrosion.

Last season's activities by the section included five section meetings and co-sponsorship of a corrosion symposium with the Chemical Institute of Canada and the National Research Council which was coincident with the meeting of Canadian Region. Topics at the section meetings were: Use of glass coatings, plant maintenance and corrosion control, rubber coatings, metallurgy and use of stainless steels and application of rigid plastics.

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Western Region to Meet Nov. 15-16 at Long Beach

The 1956 fall Western Region meeting will be held November 15-16 at Long Beach, Cal. The Lafayette Hotel will be headquarters. At a June meeting in Los Angeles, it was decided to ask University of California at Los Angeles officials to consider holding a short course November 13-14.

Coordination of material to be presented at both short course and regional meeting is planned. A schedule aimed at corrosion workers other than corrosion engineers is projected for the short course.

Convention assignments have been made as follows:

Chairman—Preston W. Hill, Signal Oil and Gas Co., Long Beach.

Program chairman—R. E. Hall, Union Oil Co., Brea, Cal.

Publicity chairman—Flora Lombardo, Coatings & Fiberglass Research Co., Los Angeles.

Facilities chairman—Harry E. Olson, City of Long Beach Municipal Gas Dept.

Education chairman—J. S. Dorsey, Southern California Gas Co., Los Angeles.

Registration chairman—J. Glenn Lacy, Amercoat Corp., South Gate.

Hospitality chairman—E. Vernon Frost, Frost Engineering Service Co., Huntington Park, Cal.

North Central Region 1957 Meeting to Be in Chicago

The 1957 North Central Region meeting will be held in Chicago at a location and time to be set later.

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Subjects for St. Louis Symposium Selected

Subjects to be discussed by four authors during the Chemical Inhibitors Symposium at the NACE 13th Annual Conference at St. Louis, March 11-15 have been given as follows by George E. Best, United Chromium Div., Metal and Thermit Corp., Baltimore, Md., chairman:

Statistical Considerations in Evaluation of Corrosion Inhibitors, Charles C. Nathan, The Texas Co., Bellaire, Texas.

Adsorption of Sulfonate Corrosion Inhibitors, A. H. Roebuck, Continental Oil Co., Ponca City, Okla.

Evaluation Tests of Inhibitors in Automobile Cooling Systems, Leonard C. Rowe, General Motors Corp., Detroit.

Economic Factors Governing Selection of Inhibitors for Air Conditioning Systems, Sidney Sussman, Water Service Laboratories, Inc., New York.

Glass in Chemical Industry Is Niagara Section Topic

"Glass in the Chemical Industry" will be the topic of the October 10 meeting of Niagara Frontier Section, first of four scheduled. The following meetings also have been planned:

November 7 or 14—Coatings and election of officers.

January 10, 1957—Stress corrosion and business meeting.

April, 1957—Joint meeting with Sewage and Water Works chapter.

Sabine-Neches Section Has 8-Meeting Schedule

Subjects for eight monthly meetings beginning with September, have been scheduled by Sabine-Neches Section. All meetings will be held at Little Mexico Restaurant, Orange, Texas.

The schedule is:

September 27—Use and Demonstration of the Corrosion Meter.

November 8—Review of papers presented at South Central Region meeting in San Antonio.

December 6—My Corrosion Problem of the Year—a panel discussion.

January 24—Metallurgist's Approach to Corrosion.

February 28—Corrosion Problems in the Chemical Industry.

March 28—Corrosion in Recirculating Cooling Water Systems.

April 25—Protective Coatings—a panel discussion.

May 23—Importance of Human Relations in Industry.

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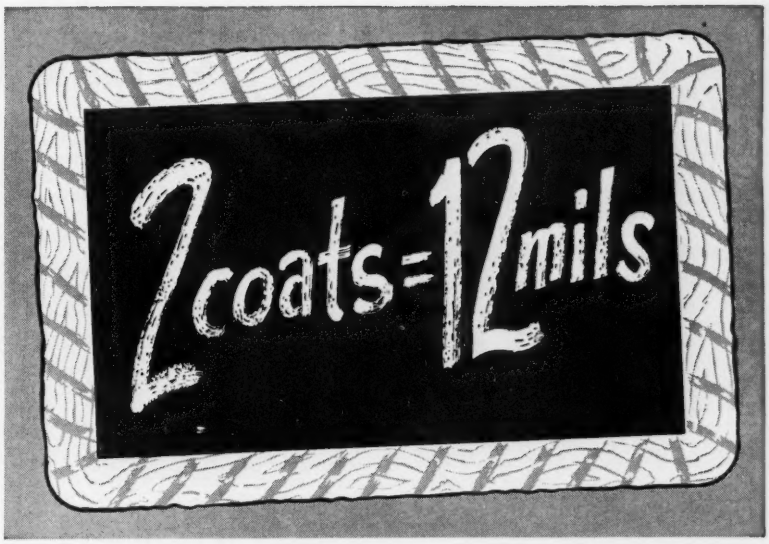

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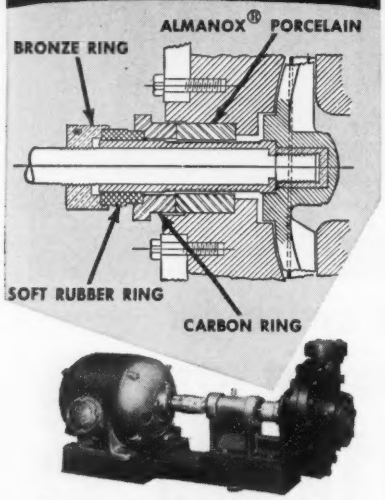

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Titles of 25 Papers to Be Given at October South Central Region Meeting Are Listed

Titles of 25 papers to be given during the South Central Region meeting at San Antonio October 23-26 are given in the following tentative program. Additional papers may be accepted before the symposia are closed.

Thursday, October 25

Corrosion in the Pipe Line Industry

Introductory remarks, L. B. Nelson, Shell Pipe Line Corp., Houston.

Effects of Variables in Laboratory Testing of Corrosion Inhibitors for Refined Petroleum Products, David B. Boies and J. L. Bregman, National Aluminate Co., Chicago.

Cathodic Protection of Compressor Stations, Pearce R. Butterfield, Transcontinental Gas Pipe Line Co., Houston.

Application of Cable in Cathodic Protection, R. G. Fisher, The Okonite Co., Passaic, N. J., and M. A. Riordan, Rio Engineering Co., Houston.

A Case History of High Temperatures on a Gas Transmission Line, A. T. Surber, Trunkline Gas Co., Houston.

Elevated and High Temperature Corrosion

High Temperature Oxidation of Iron-Nickel Alloys, M. J. Brabers and C. E. Birchenall, James Forrestal Research Center, Princeton University, Princeton, N. J.

Effect of Hot H_2S Environments on Various Metals, F. J. Bruns, Sinclair Research Laboratories, Inc., Harvey, Ill.

High Temperature H_2S Corrosion in Catalytic Refining, Cecil Phillips, Humble Oil & Refining Co., Baytown, Texas.

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Nature of Zirconium Corrosion in Water Above 200 C, R. D. Misch, Argonne National Laboratory, Lemont, Ill.

Corrosion in Oil and Gas Well Equipment

Introductory Remarks, C. C. Nathan, The Texas Co., Bellaire, Texas.

Factors to be Considered in Evaluating Corrosion Inhibitors, E. J. Simmons, Sun Oil Co., Dallas.

Chemical Principles and Corrosion Reactions, Norman Hackerman, University of Texas, Austin.

Corrosion Measurements in a H_2S-H_2O Absorption Pilot Plant, B. W. Bradley, Shell Oil Co., New York, and N. R. Dunne, Shell Oil Co., Calgary, Canada.

An Adaptation of Cathodic Protection to the Tidal Zone, M. A. Riordan, Rio Engineering Co., Houston.

Corrosion in the Utilities Industry

Introductory Remarks, Glyn W. Beesley, Dallas Power & Light Co.

Corrosion in Power Plants, Harry Blackwell, Texas Electric Service Co., Fort Worth.

Corrosion Control in the Utility Industry, A. W. Peabody, Ebasco Services, Inc., New York.

Chemical Corrosion of Lead Cable Sheaths, W. W. Elley, Southwestern Bell Telephone Co., San Antonio.

Procedures to Increase Pipe Line Enamel Coating Standards, E. C. Rogness, Lone Star Gas Co., Dallas.

Friday, October 26

Cathodic Protection

Introductory remarks, M. E. Parker, Cormit Engineering Co., Houston, chairman.

The Copper-Sulfate Electrode, Gordon N. Scott, Consultant, Los Angeles, Cal.

Rectifier Efficiencies, R. M. Wainwright, Good-All Manufacturing Co., Ogallala, Neb.

Effect of Dissolved Oxygen on Current Required for Cathodic Protection, E. Schaschl and G. A. Marsh, Pure Oil Co., Crystal Lake, Ill.

High Silicon Anodes for Cathodic Protection, W. T. Bryan and W. A. Luce, The Duriron Co., Dayton, Ohio.

Cathodic Protection of Oil Well Casing, Yale Titterington, Corrosion Services, Inc., Tulsa.

Corrosion in the Transportation Industry

Introductory remarks, J. R. Spraul, General American Transportation Co., East Chicago, Ind.

Internal Protection of Ships, L. P. Sudrabin. Electro Rust-Proofing Corp., Belleville, N. J.

External Ship Hull Protection, C. F. Schrieber, Dow Chemical Co., Freeport, Texas.

Chemically Deposited Nickel Alloy Tank Coatings for Commodity Transport, W. J. Crehan, General American Transportation Corp., Chicago.

Electrically Deposited Nickel Clad Steel for Transportation Equipment, A. R. Meyer, Graver Tank & Mfg. Co., East Chicago, Ind. and Dodd S. Carr, Bart Mfg. Corp., Belleville, N. J.

Accelerated Testing of Protective Coatings, John I. Richardson, Amercoat Corp., South Gate, Cal.

ABSTRACTS
SOUTH CENTRAL REGION
October 23-26, 1956

Effect of Variables in Laboratory Testing of Corrosion Inhibitors for Refined Petroleum Products, by David B. Boies and J. I. Bregman, National Aluminate Corporation, Chicago, Illinois.

In testing corrosion inhibitors for use in refined petroleum products careful consideration must be given to the effect of environmental conditions. Variables studied in this work include degree of agitation, concentration of dissolved solids in the water phase, temperature, oxygen content, presence of alcohol and nature of the hydrocarbon phase. A brief discussion of testing procedures is included also.

Results for a commercial automotive gasoline, aviation gasoline, jet fuel and a No. 2 fuel oil are discussed. Some inhibitors effective in sea water under dynamic conditions may be completely ineffective in sea water under static conditions; some inhibitors effective at room temperature may be required at double the concentration at 100 F and may be ineffective at 140 F at five times the room temperature concentration. The concentration of inhibitor required to protect under any specified set of environmental conditions may vary considerably with different refined products. This also may be true for different supplies of products of the same type—e.g. different gasolines.

Cathodic Protection of Compressor Stations, by Pearce R. Butterfield, Transcontinental Gas Pipe Line Corporation, Houston, Texas.

A discussion of the effectiveness of cathodic protection installations on compressor stations containing a large mass of poorly coated piping plus an extensive copper grounding system. An explanation is given of the use of buried coupons to determine the current density required for protection in areas where structure interference exists.

Application of Cable in Cathodic Protection, by R. G. Fisher, The Okonite Company, Passaic, New Jersey, and M. A. Riordan, Rio Engineering, Houston.

The selection of a cable for the connecting circuit of a cathodic protection system depends upon the environment in which the cable is to be installed. Cable construction which makes use of polyethylene covering offers the best combination for oil and chemical resistance, electrical stability and protection against mechanical damage. Data are presented to illustrate this point. A comparison between a vinyl chloride sheath and some of the other available sheathing materials is made also.

General requirements for the protection of splices and factors such as compatibility of the splicing tape with the insulations and the heat resistance of the insulation are discussed. A typical ground connection (sealed type) for either exposed or buried installation is shown.

Design factors which affect the size of conductor, overall cable diameter, current ratings in air and in earth, as well as voltage drop are presented.

(Continued on Page 82)

how to
CUT CORROSION LOSSES
a report by Koppers Company, Inc.

C. U. Pittman
Supervisor Technical Services

Good surface preparation is basic to the life and effectiveness of protective coatings. Without it, the coating cannot bond properly and may fail to prevent future corrosion.

The surface preparation method selected depends on the type of surface, the degree of corrosion, contaminants present, the desired life of the coating and the physical accessibility of the surfaces to be coated.

* * *

To remove all traces of grease or oil, vapor degreasing or solvent cleaning is necessary *before* mechanical surface preparation. Acid cleaning or pickling to remove rust and mill scale is fast and usually low in cost. After treatment, the acid should be neutralized immediately.

Hand cleaning is recommended only on small jobs, or where areas are not easily accessible. The main problem in using chisels and pointed scrapers is to avoid high ridges which cause thin spots or holidays in the coating. Power brushing and scraping are two of the more common methods of preparing surfaces. For removing rust, they are both quite effective and, usually, reasonable in cost. We have found, though, that power brushing frequently polishes surfaces too much.

Flame cleaning is a good way to remove old coatings and to heat surfaces prior to applying a thermoplastic coating. Flame cleaners are also very good for drying damp surfaces. By creating thermal shock, flamers are an effective—though slow—way to remove mill scale. Surfaces should always be wire-brushed after flame cleaning.

Blast cleaning with sand or grit has proved to be the best way to remove incrustation, rust and mill scale, and is more economical than is generally realized. Blasting is fast on even the most irregular objects. Good practice leaves the surface free of high peaks, but with shallow valleys that make good "anchors" for the coating. Care should be exercised that the air used in blasting is free of oil. Coatings should be applied immediately after blasting or the surface should be primed quickly with WP-1, two compartment type wash primer. WP-1 should also be applied if the cleaned surface cannot be completely dried.

* * *

Concrete and masonry surfaces are prepared best by hand cleaning, power brushing or chemical cleaning. Brushed surfaces should be blown clean with oil-free air, and chemical cleaners should always be neutralized, or removed by flushing, immediately. Patching and repair work should be prepared in the same manner as the original surface.

* * *

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Arabian American Oil Company
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New York 22, New York

Abstracts—

(Continued from Page 81)

High Temperature Oxidation of Iron-Nickel Alloys, by M. J. Brabers and C. E. Birchenall, James Forrestal Research Center, Princeton University, New Jersey.

New experiments on the Fe-Ni-O equilibria at 1050 C confirm the conclusions derived earlier under conditions which did not quite achieve equilibrium. The part of the ternary phase diagram including the alloy phase from 0 to about 70 percent nickel and the wüstite and spinel oxides has been constructed and several tie lines indicated in the metal-oxide two-phase fields. The three phase triangle apices have been located approximately.

The kinetic studies on iron-nickel alloy oxidation can be reconciled fairly well on the basis of the equilibria. A sequence of events is outlined consistent with the various phenomena observed.

High Temperature Sulfide Corrosion in Catalytic Reforming of Light Naphthas, Cecil Phillips, Jr., Humble Oil & Ref. Co., Baytown, Texas.

A discussion of the nature and effect of corrosion of carbon steel and several commercial alloys by hydrogen sulfide in the temperature range 600-1000 F in a catalytic naphtha reforming process. Data are presented on corrosion rates obtained both from test specimens and from measurements on equipment after various periods of operation in a 20,000 barrel-per-day catalytic naphtha reforming unit. This unit employs a fixed bed platinum-type catalyst.

Results obtained in a pilot unit investigation of the effect of sulfur content in the naphtha feed and resulting hydrogen sulfide concentration in the reaction zone on corrosion rates of several alloys in the temperature range 900-1100 F are discussed also. It was found in the pilot unit study that corrosion and scaling of existing low chromium alloys in the commercial units can be eliminated essentially by reducing the sulfur content in the naphtha feed to a level such that the maximum hydrogen sulfide concentration in the total reactor stream is 0.008 mol percent.

(Continued on Page 84)

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Abstracts—

(Continued from Page 82)

The Corrosion of Zirconium in Water Above 250 C, by R. D. Misch, Argonne National Laboratory, Lemont, Illinois.

The reaction of zirconium with water is of the gas-metal type although galvanic effects are occasionally noted. The oxidation rate is very sensitive to metal composition and no one theory can account for all observed effects. It is believed that many of the complications arise from electronic and structural changes within the oxide. These changes are influenced by surface preparation and film thickness. The aim of developing resistant alloys has been partially met in the alloy, Zircaloy-2. The oxide on this alloy is distinguished by capacitance and resistance measurements. Anodic films also have been studied and shed light on the mechanism of film formation. Physical measurements on the oxide should prove useful in future alloy development.

Factors To Be Considered in Evaluating Corrosion Inhibitors, by E. J. Simmons, Sun Oil Company, Dallas, Texas.

If a corrosion rating could be established, it follows that there could be one inhibitor better than all others, in which case there would be no need for considering any other material. Experience has shown that such a concept of rating is unrealistic, impractical and impossible. Evaluation of a particular inhibitor is rarely ever considered complete, except in the case of obvious failures. Evaluation, which consists not only of comparison but also of classification, usually consists of a laboratory phase, a limited field phase and an extended field phase, with periodic pauses to consider all available data. The longer the period of study the more reliable is the evaluation.

Actual examples of field experiences illustrate some of the factors to be considered in determining the "efficiency rating" of an inhibitor.

Chemical Principles and Corrosion Reactions, by Norman Hackerman, Department of Chemistry, University of Texas, Austin.

Corrosion reactions can be treated as are any heterogeneous chemical reactions, with the additional aspect of the possibility of reaction via an electrochemical route. The particular areas to be considered are: The thermodynamic properties of the systems, the reaction rates and reaction mechanisms, the role of material transport, the way in which adsorption may be involved and the requirements for corrosion to occur by electrochemical means.

Corrosion Measurements in a Hydrogen Sulfide Water Absorption Pilot Plant, by B. W. Bradley, Shell Oil Company, New York, N. Y., and N. R. Dunne, Shell Oil Company, Calgary, Canada.

Carbon steel corrosion rates, although very high during the first few hours or days, diminished to a tolerable level within a 19-day test. Killed carbon steel, stainless steel Type 304, Inconel and K-Monel, were resistant to sulfide stress corrosion cracking. Inconel, Monel and 304 also showed low weight loss corrosion. Hydrogen probes indicated decreasing corrosion rates in absorber and degasifying drums during the test period. Data indicate stress relieved carbon steel vessels and piping with corrosion resistant alloys for critical process parts, such as pumps, Bourdon tubes, thermometer wells, orifice plates and relief valve springs would provide acceptable service life. A water dispersable, amine type inhibitor reduced carbon steel corrosion rates and indicated protection from sulfide stress corrosion cracking.

An Adaptation of Cathodic Protection to the Tidal Zone, by M. A. Riordan, Rio Engineering Company, Houston.

Recent developments indicate the scope of cathodic protection can be extended to include the splash zone area.

A system consisting of a jacket, galvanic anodes, conducting material and other features has been designed to provide cathodic protection in the splash and tidal area. Six field installations are presently under test. Results of these field tests and other interim developments will be reported.

Corrosion Control in the Utility Industry, by A. W. Peabody, Ebasco Services, Inc., New York, N. Y.

Some of the means of corrosion control available to the utility industry including selection of materials, paints and coatings, insulation and cathodic protection, are reviewed. Examples of the type of corrosion experienced on cables and piping as experienced by gas, electric, water and communications utilities are discussed.

The effect of insufficient experience

(Continued on Page 86)

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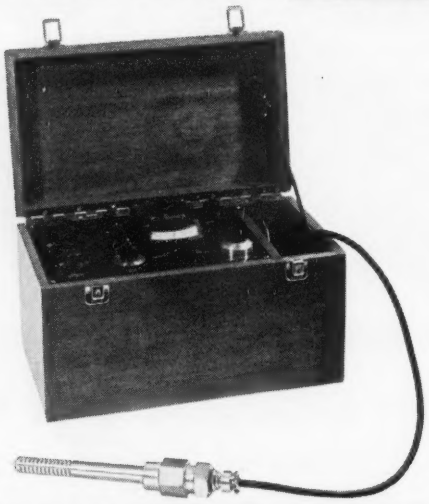

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Abstracts—

(Continued from Page 84)

and training on the results obtained from corrosion control installations are treated, with examples emphasizing situations where inadequate engineering has resulted in installations that are unnecessarily costly or detrimental to the structure being protected or to other structures.

Corrosion problems associated with electrical grounding are discussed as are present trends in the use of new grounding materials. Special applications are considered where electrolytic cells or other devices may be used to isolate structures for cathodic protection purposes and still attain adequate grounding.

The effect of progress in corrosion control on engineering design is considered. Economics is treated with emphasis on a review of some of the more important points to be kept in mind if corrosion control programs are to be economically successful.

Chemical Corrosion of Lead Cable Sheaths, by W. W. Elley, Southwestern Bell Telephone Co., San Antonio, Texas.

Differential aeration, acids and salts in the soil, foreign materials, stray currents and inter-connection of dissimilar metals all lead to corrosion of lead sheath. The first three depend on the environment itself which is usually responsible for corrosion failures of cable.

Oxygen concentration cells usually result from an accumulation of silt and mud at one point on the cable sheath while this cable is exposed to the atmosphere at another point. The contribution of acids and salts in the soil is usually more complex than is that of differential aeration cells. Reversals of potential are often seen where lead and iron are in contact in alkaline environment. In the earth, organic acids particularly contribute to lead sheath corrosion. Of the foreign materials which create corrosion problems in the lead sheath cable installations, the greatest offenders are those organic materials which form nitrates which in turn act as cathodic depolarizers.

Procedures to Increase Pipe Line Enamel Coating Standards, by E. C. Rogness, Lone Star Gas Company, Dallas, Texas.

A relatively holiday-free pipeline coating, using present standard types of coating, can be turned out by carefully schooling inspectors to look for all mechanical and human failures that might occur. These include improper heating of coating material, incomplete application, surfaces poorly prepared for bonding, etc. This plan does not incur additional expense but simply uses materials specified and avoids placing sections of pipeline in the earth without some of the coating, or all of the coatings specified. Frequently an inferior coating application results in the need for the installation of additional cathodic stations for a given pipeline. These additions in cathodic protection costs due to inferior coatings can increase installation and maintenance costs by ten times the cost of better coating application.

Rectifier Efficiencies, by R. M. Wainwright, Good-All Manufacturing Corporation, Ogallala, Nebraska.

The basis for calculation of rectifier efficiencies is given, efficiency formulas are derived, measurement methods discussed and a discussion given as to the effect of ripple components on electrochemical processes and on communication circuits. The effect of inherent constant or variable junction voltages on efficiencies is described. Some discussion is also given on the economic importance of efficiencies. The paper is directed primarily to cathodic protection rectifier applications and characteristics.

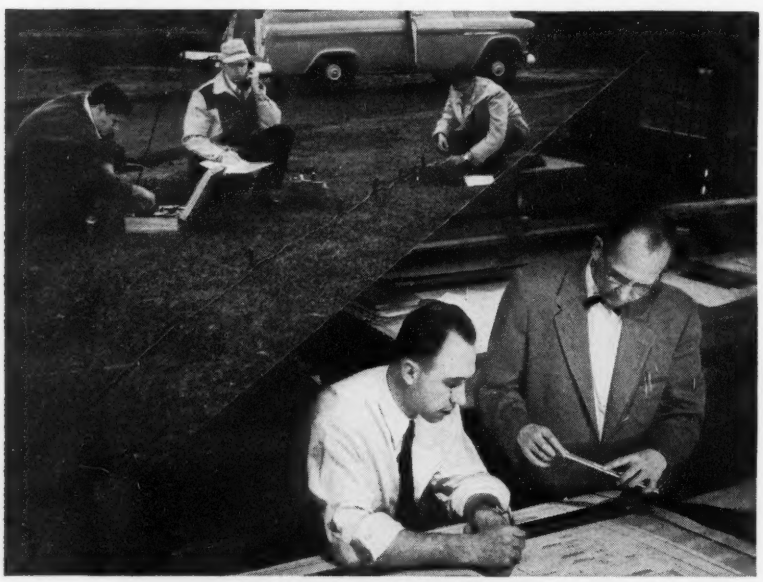
Effect of Dissolved Oxygen on Current Required for Cathodic Protection, by E. Schaschl and G. A. Marsh, The Pure Oil Company, Research and Development Laboratories, Crystal Lake, Illinois.

In a laboratory study, electrode potential and corrosion of steel were continuously measured as a function of dissolved oxygen concentration, pH, electrolyte concentration and applied current density, at 80 F. The experimental techniques developed appear to be applicable to determine the minimum current required to protect buried structures.

High Silicon Anodes for Cathodic Protection, by W. T. Bryan and W. A. Luce, The Duriron Company, Dayton, Ohio.

The use of high silicon iron anodes for impressed current systems continues to expand and up-to-date information on its range of applicability will be given. While this report will be concerned primarily with ground bed applications, information on sea water and fresh water will be included also. Current research

(Continued on Page 92)



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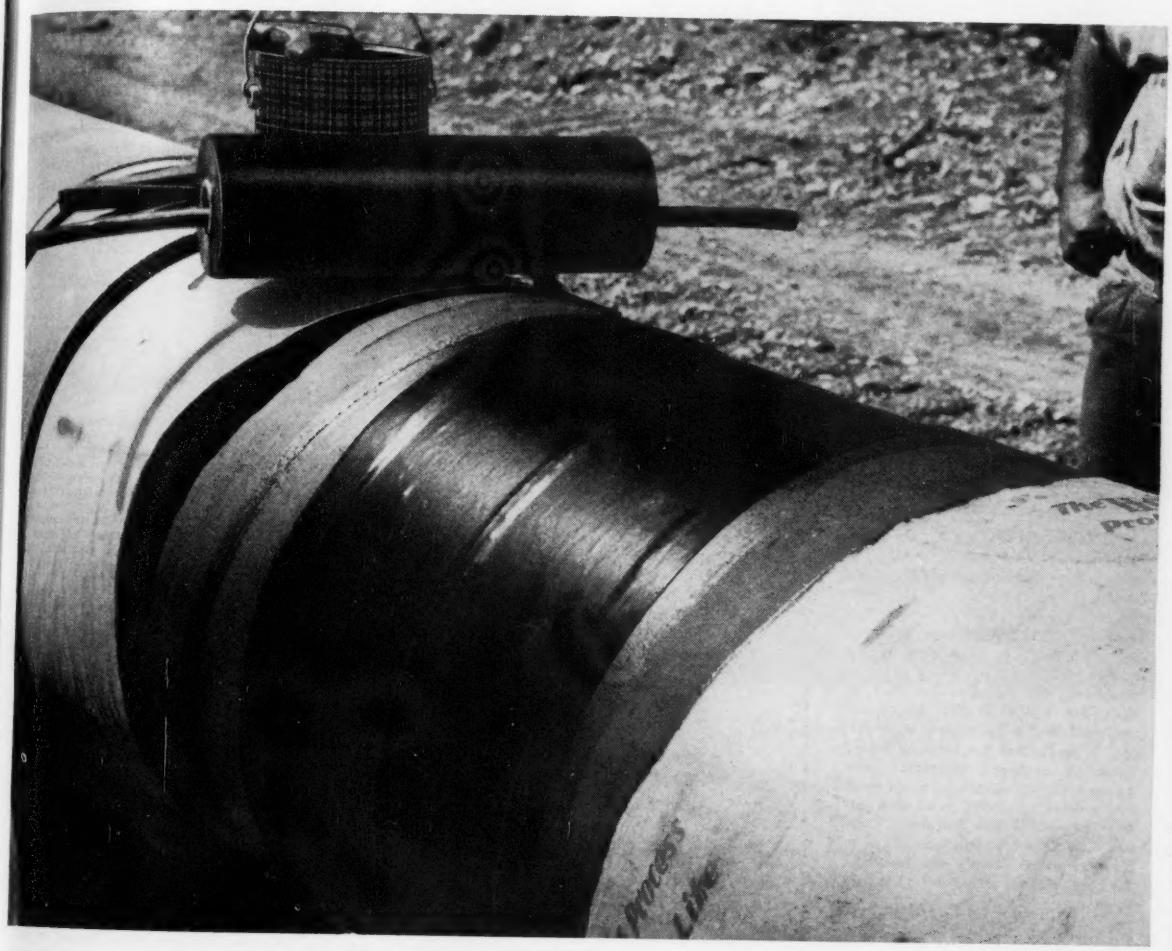

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BIOGRAPHIES

C. E. BIRCHENALL—Associate professor of chemistry, Princeton University since 1952. He holds an AB from Temple University, and MA and PhD from Princeton. From 1946 to 1952 he was a member of the staff of the Metals Research Laboratory at Carnegie Institute of Technology and during 1951-52 was assistant professor of metallurgical engineering, before leaving for Princeton. His research interests include: Diffusion of solids, oxidation of metals and alloys, thermodynamics and alloy systems. He has published numerous papers on these subjects.

M. J. BRABERS—Research Assistant, Forrestal Research Center, Princeton University. He has an engineering degree from the Technical University, Delft (1952) and a doctorate from the same institution in 1954. He is a member of the Royal Netherlands Chemical Society.

HARRY BLACKWELL—Chief chemist for Texas Electric Service Company, San Antonio since 1947. He was a student at University of Texas in chemical engineering from 1928-33 leaving to work for Texas Public Utilities Corp. as a chemist and engineer for the ice manufacturing division. He began work for his present employer in 1935 as a student engineer, becoming successively plant chemist and chief chemist. From May, 1942 to September, 1945 he was chief water tender in charge of water purification at Camp Peary, Williamsburg, Va. He is a member of Edison Electric Institute.

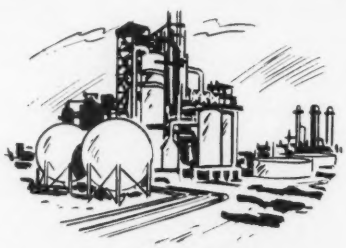
DAVID B. BOIES—He has been with National Aluminate Corp., Chicago since 1949 when he received a BS in chemical engineering from Illinois Institute of Technology. His research work is in development of corrosion inhibitors, in recent years for use in the petroleum industry.

B. W. BRADLEY—A member of the Technological staff in the Exploration and Production Department, Shell Oil Company, New York, New York. He is a 1944 graduate of Rice Institute with a BS in chemical engineering. He also has an MBA degree, 1949 from the business school at the University of Texas. Since joining Shell in 1948 he has been concerned with chemical engineering problems in production operations dealing principally with corrosion in production and gas processing facilities, treating of flood waters, and gas process design.

JACOB I. BREGMAN—Head, Physical Chemistry Laboratories, National Aluminate Corporation of Chicago, Illinois. Dr. Bregman received a BS in chemistry from Providence (R. I.) College in 1943 and an MS (1948), and a PhD (1951) in physical chemistry at the Polytechnic Institute of Brooklyn. In 1950, he joined the National Aluminate Corporation and has been with them since that time. Dr. Bregman's fields of research have included ion exchange, corrosion inhibitors, coagulation, water stabilization and investment casting.

PEARCE BUTTERFIELD—Has spent the last five years in corrosion work with Transcontinental Gas Pipe Line Corp., Houston. After graduation from University of Kansas with a BS in civil engineering he was employed successively by Phillips Petroleum Co. and

(Continued on Page 89)



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BIOGRAPHIES

(Continued from Page 88)

Trunkline Gas Co. He is a member of NACE and a registered Texas professional engineer.

N. R. DUNNE—He has a BS in chemical engineering, 1950 and an MS 1951 at the University of Saskatchewan. He joined Shell Oil Company in 1952 as an engineer in the production department. He has been concerned with corrosion and other chemical engineering problems associated with oil and gas production as well as gas plant corrosion problems in Shell's operations in Western Canada. He is a member of NACE and the Association of Professional Engineers of Alberta.

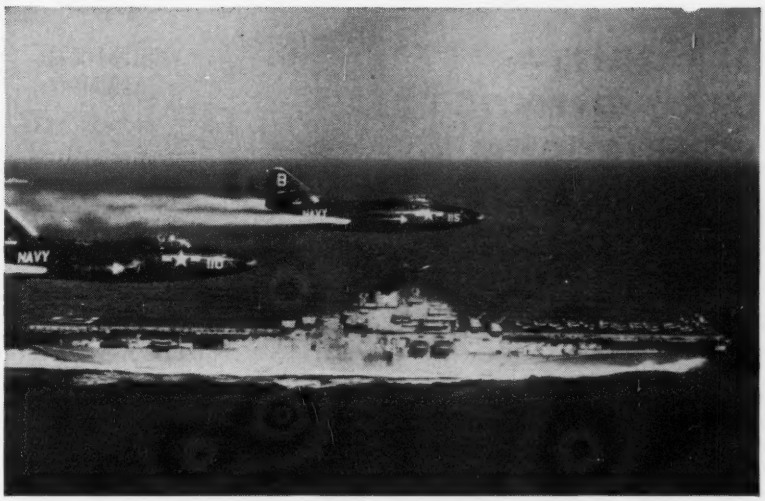
W. W. ELLEY—In charge of cable corrosion control engineering, Southwest Texas area, Southwestern Bell Telephone Company, San Antonio, Texas. Has been involved in corrosion mitigation work on telephone cables since 1953. He attended San Antonio College and the University of Texas.

NORMAN HACKERMAN—Dr. Hackerman finds time, in addition to his duties as professor of chemistry and director of the Corrosion Research Laboratory at the University of Texas, to publish with his students papers on the chemistry and physics of surfaces, adsorption and electrochemical phenomena; to be technical editor for the Journal of The Electrochemical Society and its vice-president; chairman of the NACE Inter Society Corrosion Committee, associate editor of the Monograph Board of the American Chemical Society, chairman of the NACE Education Committee and a member of several other technical associations. He has a PhD in physical chemistry from Johns-Hopkins (1935) and has served on the staffs of other universities and on the staff of the Manhattan District Project.

A. R. MEYER—Manager of welding research for Graver operating divisions. Since 1930 his principal interest has been in various aspects of welding including 12 years in research and development work. After joining Graver in 1949 he was occupied with problems associated with the welding procedures for pressure vessels and chemical processing equipment. Before joining Graver he was for five years a welding research engineer at Battelle Memorial Institute. He has a BS in welding engineering from Ohio State University and is a member of AWS, API, Tappi and ASM.

A. W. PEABODY—Electrical engineer for Ebasco Services, Inc. since his graduation from University of Maine in 1937 except for military service. Since 1939 he has been engaged in survey, design, construction supervision and adjustment of corrosion control installations for cathodic protection systems on pipe,

(Continued on Page 90)



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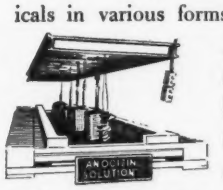

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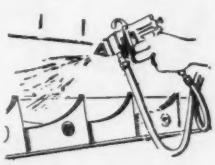

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BIOGRAPHIES

(Continued from Page 89)

CABLE AND GENERATING STATION FACILITIES. He is a frequent lecturer at NACE-sponsored short courses and active in technical committee work.

CECIL PHILLIPS, JR.—He has been employed by Humble Oil and Refining Co. since he received a BS in chemical engineering from University of Oklahoma in 1939. He is now Senior Research and Chemical Engineer in the Research and Development Division and a member of the research group that specializes in the study of corrosion problems encountered in all phases of petroleum refining operations. He is a member of NACE and ACS.

JOHN I. RICHARDSON—He has been engaged in investigation and development of corrosion-resistant protective coatings for fifteen years. After earning his bachelor's degree in chemistry at Pomona College in 1940, Mr. Richardson joined the Amercoat Corporation and has been associated with it ever since, except for a period spent in the United States Navy. During his career at Amercoat he has been chemist, chief chemist, technical services manager and technical director. The bulk of his experience relates to investigation of industrial corrosion problems and Development of protective coatings to solve them.

MAURICE A. RIORDAN—A partner in Rio Engineering Company, holds a degree in metallurgical engineering from Rensselaer Polytechnic Institute (1942). Prior to his association with Rio Engineering Company he served in the U. S. Navy and then was engaged in electrochemical research and development work with Dow Chemical Company. He has been active in corrosion work and cathodic protection since 1946.

E. C. ROGNESS—A member of NACE since 1944, he is a 1942 graduate of the American School of Electrical Engineering, Chicago and is now employed as a cathodic protection engineer by Lone Star Gas Co., Dallas. He spent six years each in cathodic protection work with the City of San Diego, Cal. and San Diego Gas and Electric Co.

GORDON N. SCOTT—Since January 1936 Dr. Scott has been a consultant on corrosion mitigation. After receiving a PhD in physical chemistry from University of California in 1926, he was employed successively by James Wakefield & Sons, Honolulu, T. H.; American Petroleum Institute as API Research Associate at the National Bureau of Standards where he studied soil corrosion; API pipe line technologist at Dallas, Texas correlating information on pipe line corrosion. He has published numerous articles and monographs on corrosion mitigation and received the 1955 NACE Frank Newman Speller Award.

E. J. SIMMONS—Supervisor of the chemical test section of the Production Service Laboratory, Sun Oil Co., Dallas, Texas. The section includes groups working on corrosion service and research, analytical testing and special problems including chemical aspects of secondary recovery. He majored in chemistry and biology at Southern Methodist University and has been with Sun since 1940.

(Continued on Page 92)

The 10-Year Index to CORROSION lists 1056 authors.

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BIOGRAPHIES

(Continued from Page 90)

L. P. SUDRABIN—Director of Engineering Services and Development of Electro Rust-Proofing Corporation, Belleville, N. J. He graduated for Northeastern University, Boston, in 1936 with a BS in chemical engineering. Prior to joining Electro-Rust-Proofing, Mr. Sudrabin occupied the positions of research engineer with the Dorr Company, chief chemical engineer with Dayton Power and Light Company and chemist with the Boston Edison Company. He is a member of the AIChE, Electrochemical Society, National Association of Corrosion Engineers, National Society of Professional Engineers and is a registered professional engineer in the states of Ohio and New Jersey. Mr. Sudrabin is chairman of several technical committees in the National Association of Corrosion Engineers. Since the beginning of 1956, Mr. Sudrabin has spent several months consulting on corrosion problems in petroleum production, pipelines, process equipment, marine structures and, ships in Lebanon, Syria, Jordan and Saudi Arabia and in the Caribbean.

Abstracts—

(Continued from Page 86)

on new materials to avoid the more difficult problems will be outlined.

Internal Protection of Ships, by L. P. Sudrabin, Electro Rust-Proofing Corporation, Belleville, N. J.

Experience in the application of cathodic protection to the cargo ballast tanks of over one hundred vessels (including clean products and sour crude tankers, combination ore-petroleum products carriers, dry cargo carriers, colliers, etc.) provides the background for the discussion on: a) Diagnosis of the corrosion problem; b) Design and application of protective current; c) Measurement of the protection achieved.

Coordination of ballast practices and cathodic protection design are needed to obtain adequate corrosion control.

Limitations of panel tests conducted in the laboratory or within operating vessels are recognized. Techniques for evaluating the protection obtained on the internal bulkhead, skin and structural member surfaces by non-destructive testing are described.

Cost of cathodic protection for adequate corrosion control of the internal cargo ballast compartments of vessels range from $.03 to $.10/sq. ft./year.

The Use of Magnesium for the External Cathodic Protection of Marine Vessels, by C. F. Schrieber, The Dow Chemical Company, Electrochemical Engineering Department, Freeport, Texas.

Experiences are presented on the use of magnesium anodes for the external cathodic protection of marine vessels. Studies over a 5-year interval reveal that the over-all hull, in addition to the much-discussed stern area, may be protected effectively by a distributed system of anodes. The variables of anode weight, optimum length and number of anode strings are related to a one- or two-year anode life. Absence of marine fouling over the same period is discussed. The keynote of economics focuses on long-term savings with no increase in short-term expenses.

Chemically Deposited Nickel Alloy Tank Coatings for Commodity Transport, by W. J. Crehan, General American Transportation Corp., Chicago, Ill.

Advantages and applicability of chemically deposited nickel alloy coatings in car tanks for standard and special service will be discussed. Corrosion data will be presented relative to commonly handled ladings and interesting application possibilities submitted.

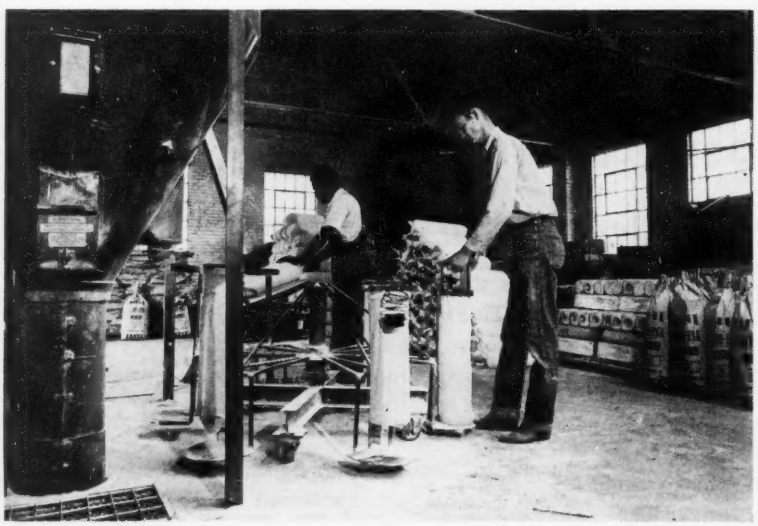
Existing facilities for lining application and design feature problems will be presented and pictures illustrating facilities and operations will be shown.

Accelerated Testing of Protective Coatings, by John I. Richardson, Amercoat Corp., South Gate, Cal.

This paper describes accelerated tests that frequently are used to indicate quickly the value of coatings for a certain job. There are no accelerated tests known that will unfailingly predict the success of a coating over long-time use. However, there are certain recognized pitfalls to avoid and certain principles which can assist in testing the coating and the various methods of application under consideration. Accelerated tests must take into account the exact environment, the type and condition of surface which is to be coated, and the conditions of application and drying. Only when *all* factors are considered can reliable tests be devised.

Cook Memorial Fund

The L. David Cook, Jr. Memorial Education Fund has been set up in memory of the late Mr. Cook, who died in the plane crash over the Grand Canyon June 30. Contributions should be sent to Robert P. Marshall, treasurer Detroit Section, 2415 Burdette Ave., Ferndale 20, Mich. Detroit Section will administer the fund.



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12 Papers Listed on Northeast Region Program

Authors of Philadelphia Technical Papers

Adams

Atkinson

Avery

Brackett

Bricknell

Caldwell

Cathcart

Hromi

Jewell

Lawrence

McNamee

McCreight

Nielsen

Orr

Renshaw

BIOGRAPHIES

HENRY W. ADAMS—Mr. Adams graduated from the University of Pennsylvania and in 1925 became associated with the Peaslee-Gaulbert Co. in market development work. In 1928, he joined U. S. Industrial Alcohol Company and later Publicker Industries. From 1948 to 1955, he was sales representative for the Amercoat Company and in 1955 became associated with the Carboline Company as a distributor. He is now consultant to Atlantic Laboratories of Delaware in Jenolite and corrosion control work. Mr. Adams is an active member of the NACE.

H. E. ATKINSON—Mr. Atkinson received a BS in mechanical engineering from Virginia Polytechnic Institute in 1937 and then joined Du Pont as a materials of construction engineer for chemical process equipment. During the past three years he has specialized in the use of plastics and held the position of Consultant Supervisor, Engineering Materials Technology. Mr. Atkinson is Chairman of Committee B-16-12 Non-Metallic Pipe Fittings of the American Standards Association, a member of Committee D-20 on plastics of the ASTM and a member of Committee 6 on the Industrial Requirements of Plastic Materials of the Chemical Advisory Board.

RICHARD E. AVERY—Mr. Avery received a BS in metallurgical engineering from Rensselaer Polytechnic Institute in 1950. He joined the Pfaudler Co. that same year and was appointed chief metallurgist in 1953. He is a member of the American Welding Society and the American Society for Metals.

(Continued on Page 94)

Coatings, Statistics, New Alloys, Plastics Are Session's Topics

A program geared to the industrial interests of the area has been prepared for the Northeast Region's Philadelphia meeting October 15-17 at the Drake Hotel. Symposia have been prepared on protective coatings, application of experimental design and analysis to corrosion problems, plastics and new alloys and ceramics. First day of the meeting has been reserved for technical committees.

The program is:

Monday, October 15

Technical committee meetings all day.

Tuesday, October 16

Registration all day.

7:30 am—Authors' breakfast.

9 am—Formal opening of conference: Frank E. Costanzo, chairman, Northeast Region. Thomas F. Degnan, chairman, Philadelphia Section.

9:10 am—Survey of the conference program, John P. G. Beiswanger, General Analine and Film Corp., program chairman.

9:15 am—Introduction to Session 1: Protective Coatings, James H. Cogshall, Corrosion Engineering Products Dept., Pennsylvania Salt Mfg. Co., Philadelphia.

9:20 am—Chemical Surface Preparation of Steel, Henry W. Adams, Consultant, Atlantic Laboratories of Delaware, Inc., Wilmington, Del.; Frank S. Brickness, Chief, Building and Marine Div., Technical Dept., Jenolite, Ltd., London, England; John H. Lawrence, Managing Director, Jenolite, Ltd., London, England.

10:10 am—An Examination of Epoxy-Type Industrial Maintenance Coatings, William M. Brackett, Truscon Laboratories, Division of Devoe & Raynolds Co., Inc., Decatur, Ga.

11 am—Suggested Specification for the Purchasing and Acceptance of Applied Tank Lining Materials, Wallace P. Cathcart, President, Tank Lining Corp., Pittsburgh.

2 pm—Introduction to Session 2: Application of Experimental Design and Analysis to Corrosion Problems, J. James Hur, Atlantic Refining Co., Philadelphia.

2:05 pm—Some Concepts of Experimental Design, John J. Hromi, Head, Statistics Section, United States Steel Corp., Applied Research Laboratory, Monroeville, Pa.

2:55 pm—Analysis of Variance, J. C. Whitwell, Chemical Engineering Dept., Princeton University, Princeton, N. J.

3.45 pm—Use of Some Statistical Methods in Corrosion Investigations, James R. Caldwell, Research Chemist, James G. Jewell, Section Head, Corrosion Section, Materials Engineering Div., Gulf Research and Development Co., Pittsburgh.

Wednesday, October 17

7:30 am—Authors' breakfast.

9 am—Comments by regional chairman.

(Continued on Page 94)

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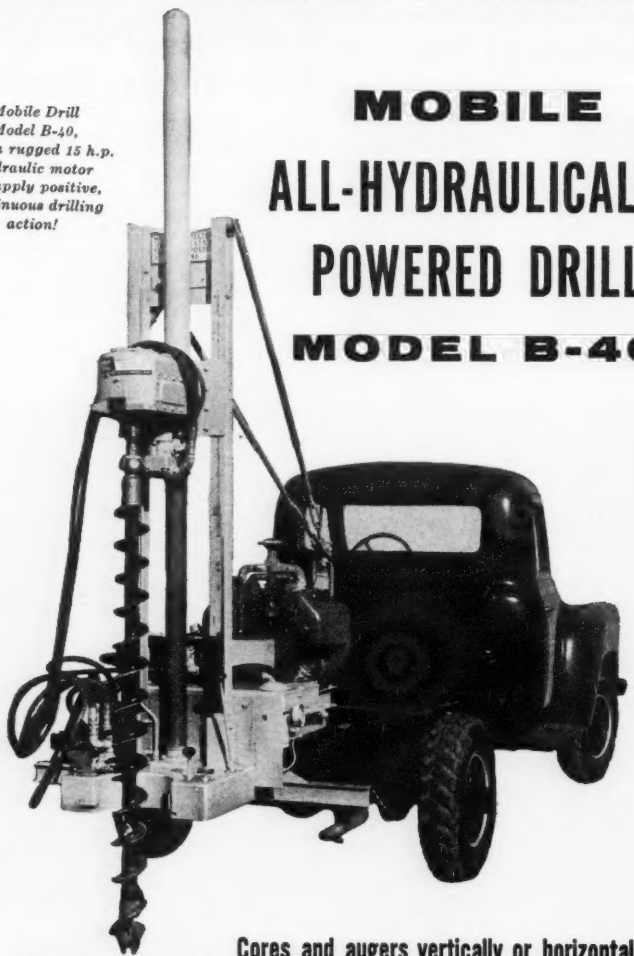

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12 Papers—

(Continued From Page 93)

9:05 am—Introduction to Session 3: Plastics, Walter H. Burton, Chairman; General Chemical Div., Allied Chemical and Dye Corp., Camden, N. J.

9:10 am—What's New in Corrosion Control Using Teflon, George C. Nielsen, Polychemical Dept., E. I. duPont de Nemours & Co., Wilmington, Del.

10 am—New Elastomeric Materials of Construction, James P. McNamee, chemist, U. S. Rubber Co., Providence, R. I.

10:50 am—Plastics in the Chemical Industry, H. E. Atkinson, Consultant Supervisor, Engineering Materials Technology, Engineering Dept., E. I. duPont de Nemours & Co., Wilmington.

2 pm—Introduction to Session 4: New Alloys and Ceramics, J. Byron Godshall, Metallurgist, Ingersoll-Rand Co., Phillipsburg, N. J.

2:05 pm—Corrosion Resistance of Low Nickel and Nickel-less Stainless Steels, William G. Renshaw, Corrosion Section, Research Laboratories, Allegheny Ludlum Steel Corp., Brackenridge, Pa.

2:55 pm—Fabrication of Titanium, Richard E. Avery, Chief Metallurgist, The Pfaudler Co., Rochester, N. Y.; Stanley C. Orr, Assistant Factory Manager, Elyria Div., The Pfaudler Co., Elyria, Ohio.

3:45 pm—Recent Developments in Ceramics for Application in Corrosive Atmosphers, Louis R. McCreight, Manager, Advance Material Studies, Aero-Sciences Lab., Special Defense Projects Dept., General Electric Co., Philadelphia.

BIOGRAPHIES

(Continued From Page 93)

WILLIAM M. BRACKETT—Mr. Brackett received a BS in chemistry at the University of Chattanooga in 1950 and then joined Devoe and Raynolds in Maintenance Product Development Laboratories. He became sales engineer with Truscon Laboratories Division in 1955.

FRANK S. BRICKNELL—Mr. Bricknel formerly was a technical officer of the British Gas Board and a technical consultant. He also operated his own company manufacturing anti-corrosion materials, has been with Jenolite Ltd. for six years and is now Chief of the Building and Marine Division, Technical Dept.

JAMES R. CALDWELL—Mr. Cadwell received a BS in chemistry from Yale University and was associated with the Carnegie-Illinois Steel Corp. in Pittsburgh, Pa. and The Shell Oil Company in Houston, Texas before joining Gulf. At present, he is Research Chemist, Corrosion Section, Materials Engineering Division, Gulf Research and Development Co., Pittsburgh, Pa.

WALLACE P. CATHCART—Mr. Cathcart received a AB degree from Washington and Jefferson College. He is an active member of the firm, Cathcart and Moore Company and has been president of Tank Lining Corp. since it was incorporated in 1950. As an active member of the NACE, he has served as an officer of the Pittsburgh section for several years and served on various technical committees. Mr. Cathcart was co-chairman in 1955 and chairman in 1956 of the Protective Coatings Symposium at the national NACE conferences.

JOHN D. HROMI—Mr. Hromi obtained a BS in mathematics from Carnegie Institute in 1948 and then was granted a BS in electrical engineering from Clemson College in 1950 and an ML from the University of Pittsburgh in 1951. Before college, he was employed by the Fort Pitt Steel Casting Co. of McKeesport, Pa. and the Rust Engineering Co. of Pittsburgh, Pa. After he received his ML degree, he joined the United States Steel Corporation. At present, he is Head, Statistics Section of the United States Steel Corp.'s Applied Research Laboratory in Monroeville, Pa. Mr. Hromi is a member of the American Statistical Association, the Institute of Mathematical Statistics and the American Society for Quality Control.

(Continued on Page 95)

BIOGRAPHIES

(Continued From Page 94)

JAMES G. JEWELL—Mr. Jewell received a BS in chemical engineering from Rice Institute and MS in chemical engineering from Cornell University. After joining Gulf Oil Corp., he assumed his present position of Section Head, Corrosion Section, Materials Engineering Division, Gulf Research and Development Co., Pittsburgh, Pa.

JOHN H. LAWRENCE—Mr. Lawrence joined International Forwarding Agents, Ltd., Covent Garden, London, England shortly before World War II. While there, he developed RRNI, a rust remover. A sister company, Jenolite, Ltd., was resuscitated and the product called Jenolite. Lawrence became general manager of Jenolite, Ltd. and a year later was named managing director, the position he now holds.

LOUIS R. McCREIGHT—Mr. McCreight received a BS in ceramic engineering from the University of Illinois in 1946 and a MS in ceramic engineering from the same school in 1946. He was Research Assistant on the Manhattan Project in 1944 and 1945 and in 1949 joined General Electric as a ceramist at Knolls Atomic Power Laboratory. This year he was named Manager, Advance Materials Study of the Aero-Science Laboratory, Special Defense Projects Dept. Mr. McCreight is past chairman of the Refractories Division, American Ceramic Society and a member of Sigma Xi.

JAMES P. McNAMEE—Mr. McNamee received a BS in chemistry from Providence College. He joined the U. S. Rubber Company in 1939 and has specialized in the use of natural and synthetic rubber for tank linings and roll coverings. At present, he is a chemist with that organization. Mr. McNamee is a member of the American Chemical Society, Rubber Division and the NACE.

GEORGE C. NIELSEN—Mr. Nielsen received a BS in chemistry from Washington and Lee University in 1940 and then joined Du Pont where he has been concerned with the development and production of vitreous enamels and synthetic resin-based finishes and more recently, plastics. At present, he is a Teflon representative for Du Pont. Mr. Nielsen is a member of Chi Gamma Theta Honorary Chemical Society, the Society of Plastic Engineers and the NACE.

STANLEY C. ORR—Mr. Orr received a BS in ceramic engineering from Alfred University in 1937 and has done post graduate study in ferrous metallurgy at Penn College. He joined the Pfaudler Co. after graduation from college as assistant ceramist, later became chief ceramist and was then appointed to his present post of Assistant Factory Manager of the Elyria Division. Mr. Orr is a member of the American Welding Society and the American Society for Metals.

WILLIAM G. RENSHAW—Mr. Renshaw received a BS in chemical engineering from Pennsylvania State University and has been with the Allegheny Ludlum Steel Corp. for the past 14 years. At present, he is Research Supervisor of the Corrosion Section of the Research Laboratories of that Company. He is an active member of NACE having held various offices in the Pittsburgh Section. He has just completed a term as chairman there.

ABSTRACTS

Northeast Region Meeting
October 15-17, 1956

Chemical Surface Preparation of Steel, Henry W. Adams, Atlantic Laboratories of Delaware Inc., Wilmington, Del.; Frank S. Bricknell, John H. Lawrence, Jenolite, Ltd., London, England.

Discussion of protective measures, particularly chemical treatments applied to steel structures of all kinds prior to painting. Particular emphasis on the use of de-jellies, rust removal and a self-neutralizing phosphating process.

An Examination of Epoxy-Type Industrial Maintenance Coatings, William M. Brackett, Truscon Laboratories, Division of Devoe and Raynolds Co., Inc., Decatur, Georgia.

A discussion of the application of epoxy coatings to existing steel structures in various industries which were not designed for corrosion protection. Case history studies from a cross-section of these industries will furnish data on practical surface preparation methods, as well as practical application methods.

Suggested Specifications for the Purchasing and Acceptance of Applied Tank Lining Materials, Wallace P. Cathcart, Tank Lining Corp., Pittsburgh.

A discussion of the need and reasons for specifications in the purchasing and acceptance of lined vessels and piping including procedures used by various companies. Suggested specifications will be outlined and inspection techniques, as well as a guide for preparing inspection specifications, will be given.

Some Concepts of Experimental Design, John D. Hromi, Head, Statistics Section, United States Steel Applied Research Laboratory, Monroeville.

A discussion of new developments which enable the investigator to use each piece of data for making each conclusion and enable him to examine the behavior of one variable at more than one level of each of the other variables in the study. These new developments make it possible to answer questions heretofore unsolvable.

Use of Some Statistical Methods in Corrosion Investigations, James R. Caldwell, Research Chemist, Corrosion Section, Materials Engineering Division, Gulf Research and Development Co., Pittsburgh; James G. Jewell, Section Head, Corrosion Section, Materials Engineering Division, Gulf Research and Development Co., Pittsburgh.

A discussion of the application of sev-

(Continued on Page 96)

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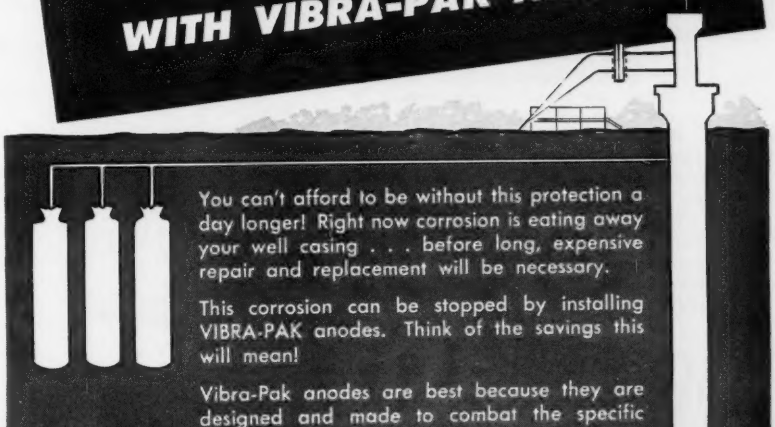

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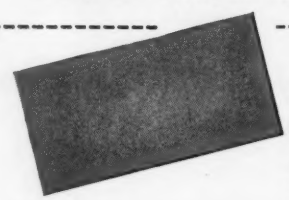

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Abstracts—

(Continued From Page 95)

eral techniques of experimental design and statistical analysis to laboratory and field investigations of corrosion, with emphasis on corrosion of marine oil tankers. Various statistical methods, as well as the importance of simultaneous laboratory and field tests are discussed.

What's New in Corrosion Control Using Teflon, George C. Nielsen, Polychemicals Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.
A discussion of new forms of the raw material and new fabricating techniques involving Teflon which have made possible new applications in combating corrosion. Field test data will be revealed and their significance discussed.

New Elastomeric Materials of Construction, James P. McNamee, Chemist; U. S. Rubber Company, Providence, Rhode Island.
A discussion of two new synthetic rubbers, chlorosulfonated polyethylene and high temperature butyl and the useful materials of construction that are being made from them. Physical and chemical properties will be given and various uses described in detail.

Plastics in the Chemical Industry, H. E. Atkinson, Consultant Supervisor; Engineering Materials Technology, Engineering Department, E. I. du Pont de Nemours & Co., Inc.; Wilmington, Del.
A discussion of the specific techniques of design, fabrication and installation of plastic materials of construction necessary for successful and economic application. Current and potential applications of plastics will be used to illustrate problems with emphasis on piping and ventilating systems.

Corrosion Resistance of Low Nickel and Nickel-Less Stainless Steels, William G. Renshaw, Research Supervisor; Corrosion Section, Research Laboratories; Allegheny Ludlum Steel Corp., Brackenridge, Pa.
A discussion of the corrosion resistance of newly developed low nickel and nickel-free stainless steels in fields where chromium nickel steels have been previously employed. Corrosion tests on these materials will be reviewed and modifications of these steels for special purposes will be described.

Fabrication of Titanium, Richard E. Avery, Chief Metallurgist; The Pfaudler Co., Rochester, N. Y.; Stanley C. Orr, Assistant Factory Manager, Elyria Division, The Pfaudler Co., Elyria, Ohio.
A discussion of the forming of titanium into various shapes for use in chemical equipment, including the use of inert gas welding methods and results obtained. The fabricating properties of zirconium are compared to those of titanium.

Recent Developments in Ceramics for Application in Corrosive Atmospheres, Louis R. McCreight, Manager; Advance Material Studies, Aero-Sciences Laboratory, Special Defense Projects Dept., General Electric Company, Philadelphia, Pa.
A discussion of developments, tests and applications in the fields of enamel, glass and refractories as applied to corrosion resistance, particularly at elevated temperatures. Application in the chemical, metallurgical and nuclear energy fields will be surveyed.

GENERAL NEWS

Numerous Corrosion Papers on ASTM Program

225 Technical Papers To Be Given During Los Angeles Session

Two hundred and twenty-five technical papers in 43 sessions are scheduled to be given during the September 17-21 Second Pacific Area National Meeting and Apparatus Exhibit of American Society for Testing Materials to be held at Hotel Statler, Los Angeles.

Among the papers likely to be of interest to corrosion workers are:

Symposium on Turbine Oils

Rusting in Turbine Oiling Systems, N. W. Furby, F. J. Hanly, California Research Corp. and J. A. Vincent, Standard Oil Co. of Cal.

Monolayers of Anti-Rust Additives, H. E. Ries, H. D. Cook and C. M. Loane, Standard Oil Co .(Ind.).

Symposium on Lubricating Oils

Direct Determination of Metals in Used Engine Oils by Emission Spectroscopy, W. D. Perkins, Shell Oil Co.

Direct Reading Spectrographic Evaluation of Used Railroad Oils, V. C. Barth, Chicago and Northwestern Railroad System.

Symposium on Properties, Tests and Performance of Electrodeposited Metallic Coatings

Corrosion Behavior and Protective Value of Decorative Copper-Nickel-Chromium and Nickel-Chromium Coatings on Steel, C. H. Sample, International Nickel Co.

Comparison of the Corrosion Behavior and Protective Value of Electrodeposited Zinc and Cadmium Coatings on Steel, C. H. Sample and R. B. Teel, International Nickel Co. and A. Mendizza, Bell Telephone Laboratories.

Atmospheric Exposure of Electroplated Lead Coatings on Steel, A. H. DuRose, Harshaw Chemical Co.

The Standard Salt Spray Test—Is It a Valid Acceptance Test?, A. Mendizza, Bell Telephone Laboratories.

Non-Ferrous Metals

Pit Depth Measurements as a Means of Evaluating the Corrosion Resistance of Aluminum in Sea Water, T. J. Summerson and M. J. Pryor, Kaiser Aluminum and Chemical Corp.

Symposium on Radiation Effects of Materials

Effect of Irradiation on Some Plastic Materials, O. Sisman, Oak Ridge National Laboratory.

Symposium on Industrial Waste and Industrial Waste Water

Industrial Waste Problems in Southern California, T. C. Wilson, Los Angeles Bureau of Standards.

Water Pollution Control in the Los Angeles Area, C. B. Johnston, Pomeroy and Assoc.

New Methods for Handling Plating Wastes, W. W. Morrison, Illinois Water Treatment Co.

The Use of Organic Flocculating Aids in Treatment of Industrial Water and Industrial Waste Water, J. K. Rice, Cyrus Wm. Rice & Co.

Symposium on Paint

Silicones in the Protective Coatings Industry, H. L. Cahn, General Electric Co.

Surface Treatments for Metals Prior to Painting, A. J. Tuckerman, Bradley Paint Co.

Vinyl Coatings, C. I. Spessard, Bakelite Company.

Protective Coatings for the Railroad Industry, G. J. Grieve, Pacific Paint and Varnish Co.

Evaluation of Paints and Protective Coatings for Municipal Use, J. H. Rigdon, Los Angeles Bureau of Standards.

Examination and Evaluation of Protective Coatings on Steel in Marine Environments, L. L. Whiteneck, Long Beach Harbor Dept.

Control of Phosphating Systems, S. Spring, Kelite Corp.

Why Paint Specifications? Their Tests and Controls, C. F. Pickett, Aberdeen Paint and Chemical Laboratory.

Deterioration Prevention Symposium Is Scheduled

A three-day symposium on Prevention of Equipment Deterioration will be at the U. S. Naval Civil Engineering Research and Evaluation laboratory, Port Hueneme, Cal. October 23-25. Sponsored by the Bureau of Yards and Docks, it will provide a forum for industry and the military to review efforts and reassay problems associated with protection of vehicles.

Representatives of research centers and professional groups and manufacturers are invited to attend to hear papers including some on preservation of equipment by means of corrosion inhibitors. More information can be obtained from Officer in Charge, Code 2005E4, U. S. Naval Engineering Research and Evaluation Laboratory, Construction Battalion Center, Port Hueneme, Cal.

R. B. Mears, Director of Applied Research Laboratories, U. S. Steel Corp. is a member of a panel scheduled to review the symposium on 25 October.

Plastics Abstracts Service Is Offered in England

British Plastics Federation, 47-48 Picadilly, London, W. 1, England is offering an abstracting service on technical articles in journals throughout the world dealing wholly or partly with plastics developments. The service includes patents from countries with important plastics industries.

ISA Conference Has Several Papers of Corrosion Interest

Papers scheduled for presentation at the September 17-21 Instrument Society of America Conference in New York include the following of interest to corrosion workers:

Wednesday, Sept. 19. Evaluation of the Accuracy of the Potentiometer Method of Measuring Resistance, Robert E. McCallum and Jack I. Wilson, Sandia Corp., Albuquerque, N. M.

Thursday, Sept. 20. Analysis Instrumentation—Air Pollution Measurement.

The Sulfur Dioxide Autometer, Moyer D. Thomas, Stanford Research Institute, Menlo Park, Cal.

Problems in the Detection of Air Borne Pollutants, Morris Katz, Dept. of National Health and Welfare, Ottawa, Ont., Can.

Recording Colorimeters and Recording Spectrometers for Air Pollution Measurements, N. A. Renzetti and L. H. Rogers, Air Pollution Foundation, Los Angeles, Cal.

A Versatile Automatic Dosage Rate Recorder for Air Pollution Studies, D. F. Adams, H. J. Dana and R. K. Koppe, Div. of Ind. Research, Washington State College, Pullman, Wash.

Use of the Titrilog in Air Pollution Studies, D. F. Adams, H. J. Dana and R. K. Koppe.

Ultrasensitive Conductometric Measurement of Sulfur Dioxide in Air, Morris B. Jacobs, Dept. of Air Pollution Control. New York, N. Y.

Instrumental Techniques Used in Air Pollution Training and Research at the R. A. Taft Sanitary Engineering Center, C. C. Robson and H. J. R. Stevenson, U. S. Public Health Service, Cincinnati, Ohio.

Added Aluminum Benefits Steel Used at Over 800 F

Addition of ¾ lb. maximum aluminum per net ton of steel to be used at 800 F. or above is recommended in a specification prepared by Committee A-1 on Steel of the American Society for Testing Materials. New specifications for pressure vessel work, paralleling present Specifications A 201, 212 and 285 but containing an additional provision for low residual copper content also have been issued.

The clause requiring addition of aluminum was added to Specifications A 201, 212 and 204 to prevent graphitization in high temperature service. The clause stipulates also the steel should have a McQuaid-Ehn grain size of 1 to 4.

the lifetime of the Coating is the lifetime of . . .

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COROMAT

. . . a flexible mat, made from glass fibers bonded with an elastic resin, reinforces enamel on underground pipe. Coromat adds strength, where strength is needed, to the coating during application and in service.

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PIPE LINE PRODUCTS CO.
Box 1886 Tulsa, Oklahoma

BOOK REVIEWS

Contributions of J. M. Person to Mitigation of Underground Corrosion. 56 pages, 8½ x 11, paper. 1956. National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas. Publication 56-12. Per copy, $5.

Six papers by the late Dr. J. M. Pearson, an acknowledged expert on underground corrosion mitigation and one by a co-worker prepared under his leadership, are reprinted. The six papers, reprinted by permission from The Petroleum Engineer and Transactions of The Electrochemical Society where they were published originally in 1941-44, cover electrical examination of coatings, "Null" methods, determination of current required, concepts and methods of cathodic protection and preventive maintenance by inspection. The newcomer and long-time worker on underground corrosion problems alike will find these papers include useful information.

ASTM Standards on Copper and Copper Alloys. 637 pages, 5¾ x 8¾ inches, paper. December, 1955. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy, $5.75.

The latest form of 127 ASTM Standards—110 specifications, 12 test methods, two recommended practices, two classifications, of copper and copper-base alloys and one definition of terms are included in this book. Data were developed by ASTM Committee B-5 on Copper and Copper Alloys, Cast and Wrought and related standards developed by Committees B-1 on Wires for Electrical Conductors and B-2 on Non-Ferrous Metals and Alloys.

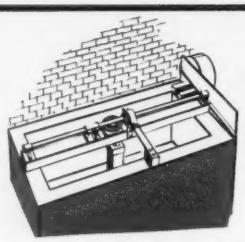
Fifty of the specifications included have been revised since the previous edition was issued and a new specification for threadless copper pipe has been added. There are indices by number and alphabetical subject.

Electrochemical Behavior of Tellurium. Diagrams of the Equilibrium Tension-pH of System TeH_2O at 25 C. (In French.) 26 Pages, 8¼ - 11¾ inches, paper. April, 1956. By E. Deltombe, N. deZoubov and M. Pourbaix. Centre Belge d'Etude de la Corrosion, 21 Rue Drapiers, Bruxelles, Belg. Price not indicated.

The study gives free enthalpies of standard formation at 25 C, reactions and equilibrium formulae, and diagrams of equilibrium tension-pH and interpretation. There is a bibliography of 47 references and three figures.

Symposium on Metallic Materials for Service at Temperatures Above 1600 F. 193 pages, 6 x 9, paper. February, 1956. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy $3.

Fourteen papers presented at a symposium during the June, 1955 annual meeting of ASTM. Papers cover data on materials for jet engine buckets, influence of boron, effect of heat treatment on Nimonic alloys, stress rupture properties of Inconel 700, chromium-nickel alloys for high temperature service, effect of rare earth additions; creep, rupture and notch sensitivity properties of S-816 alloy; titanium-carbide base cermets, molybdenum-rich alloys, tension and torsion tests on Nimonic alloys, thermal shock testing and zirconium-rich alloys. Discussions are included.



After 5 years
TOREX® ENAMEL
still protects alum tanks
AT Celanese
CORPORATION OF AMERICA

Alum solution in the concrete tanks at Water Filter Plant, Celanese Corporation, Belvidere, N. J., was eating through the concrete and loosening the mortar in the brick wall behind the tanks. That was back in 1951. Celanese engineers consulted Inertol Co., Inc., manufacturers of specialized coatings. Inertol®s Torex Enamel was used.

For more than five years now, that first application of tile-smooth Torex has been protecting the tanks. No more concrete disintegration, leaks, downtime, repairs.

Torex Enamel is a chlorinated natural rubber-base coating, in color. It's easily cleaned, resists water-treatment chemicals. Today, send for free informative folder, "Inertol Chemical-Resistant Enamels" C-571. No obligation. Write your name, title, firm name and address in margin of this page and mail.

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Midland Coatings Society Plans Six Meetings Yearly

A group of persons concerned with coatings, including polymer research, application research, technical service, production, market research and sales has organized the Midland Coatings Society. Composed principally of employees of Dow Chemical Company and Dow-Corning Corp., the group's aim is to stimulate interest in the coatings industry and foster closer relations among personnel.

Six scheduled meetings are planned during the fiscal year covering topics related to the paint, textile, and paper fields and to maintenance problems. Outside speakers will be sought. First program is scheduled in October.

Corrosion Products Block Electrical Contacts Study

Extremely thin films of corrosion products and other contamination of electrical contact surfaces have blocked successful development of a reproducible test for surety of make of electrical contacts. This was reported during the June 12-13 meeting at Swampscott, Mass of the Electrical Contacts subcommittee of Committee B-4 on Electrical Heating, Electrical Resistance and Electrical Contacts of the American Society for Testing Materials.

THE SOLUTION: COREXIT—

Humble's Proven Corrosion Preventives

Among the Humble *Corexit* formulas, several are designed to meet the many unusual requirements for corrosion prevention in gas condensate wells and their allied operations. In wells where temperatures and pressures are high, *Corexits* have proven especially effective; and can be used safely under these conditions.

Your operating costs will be lower when you use *Corexit* because fewer well pulling and work-over jobs are necessary, and the life of your equipment is prolonged.

For complete information on *Corexit*, see your nearest Humble wholesale plant in Texas and New Mexico, or write or phone:

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Sales Department
Humble Oil & Refining Company
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HUMBLE OIL & REFINING COMPANY

Equipment Services NEW PRODUCTS Materials Literature

Michigan Chrome and Chemical Co. Detroit has purchased the assets of Pyramid Plastics Co., Chicago.

•

Bart "Flex Seal" Centrifugal Pumps are described in a 4-page catalog section available from Bart Laboratories, 229 Main St., Belleville, N. J.

•

Annin small flow control valves designed for working pressures up to 6000 psi are now available from The Annin Company, 6570 East Telegraph Road, Los Angeles 22, Cal.

Garfield Chemical and Mfg. Corp. is expanding sulfuric acid production to 1100 tons daily by constructing its fifth contact process plant at Garfield, Utah. It will use sulfur dioxide gas produced by the Garfield Smelter of American Smelting and Refining Co.

•

Solder Fluxes, quick wetting and non-corrosive designed primarily for use on copper and copper-base alloys are being manufactured by Federated Metals Div., American Smelting & Ref. Co. Known as Federated H-series Solder Fluxes they use safe to handle derivatives of hydrazine. The flux decomposes and vaporizes during soldering, leaving virtually no residue.

•

MD Enamel, an organic coating designed for use on home appliances now under test by Du Pont's Finishes Division is said to be the most durable coating ever developed for this purpose. Based on a new polymer, it is said to be very much harder than currently used enamels and considerably more resistant to marring and chipping. It is virtually unaffected by prolonged exposure to high temperature soap solutions.

•

Corrosion Control and research departments of Dow Chemical Company at Freeport, Texas were inspected by representatives of 27 major oil and chemical companies June 14. C. F. Schrieber, of the electrochemical engineering department's cathodic protection development section outlined the history of Dow's corrosion control work. Applications of cathodic protection systems were inspected under guidance of Fowler Hart, superintendent of the Texas Division's Instrument Technical Service Department.

•

SO-100 Magnaflux Sonizon, a portable cathode tube ultrasonic thickness measuring instrument has an accuracy of plus or minus one percent of thickness. With accessory equipment readings of thicknesses up to five inches can be made. More information can be obtained from Magnaflux Corp., 7300 West Lawrence Ave., Chicago 31, Ill.

•

Thermo Materials, Inc., 1275 Harrison St., San Francisco, organized to develop and produce high temperature precision industrial ceramics will occupy a site near Menlo Park, Cal. Ceramic and cermet parts for electronic, atomic, aircraft, rocket and jet engine industries will be made.

•

Vanadium Corp. of America has moved its engineering department from Niagara Falls, N. Y. to new facilities at Cambridge, Ohio.

•

Allied Products Div. of Hamilton Watch Co., Lancaster, Pa. has developed a means of heat treating small precision stainless steel parts for instruments after they have been finished. It is said to be effective for all hardenable grades of stainless steel and will produce both toughness and hardness. The process can be regulated to produce controlled amounts of growth or shrinkage as well as maintain original dimensions.

•

Badger Manufacturing Co., Cambridge, Mass. is one of the companies named by the National Research Corp. to construct a zirconium processing plant at Pensacola, Fla.

•

Tube Turns, Louisville, Ky. has purchased 13 acres adjacent to its Louisville plant for expansion.

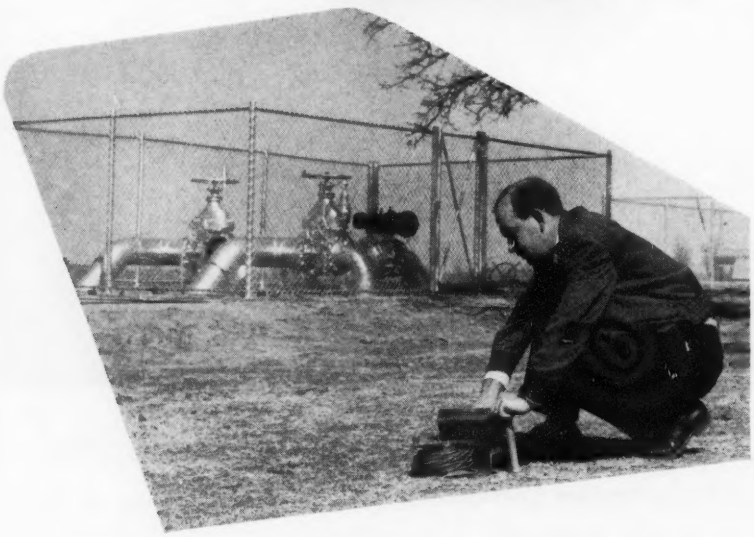
•

Architectural Alodine, a green toned

(Continued on Page 102)

AN-SPEC

COMPREHENSIVE SURVEYING



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- QUALITY MATERIALS
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Comprehensive surveying is just one of several services so important to the final results you will obtain from cathodic protection. Pipe Line Anode Corporation offers every service needed for scientific protection against costly corrosion. AN-SPEC magnesium anodes are guaranteed for high purity. It takes top quality product and specialized, complete service for best results. Call us today.

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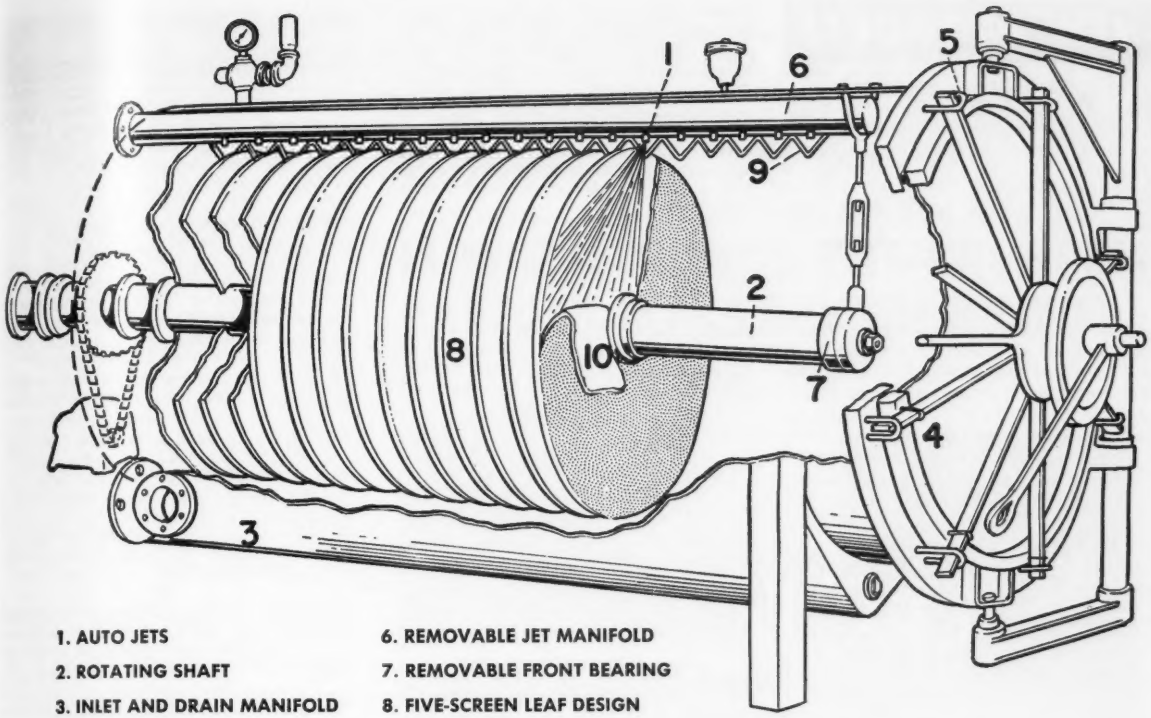

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10. ASBESTOS PRECOAT

INCO NICKEL ALLOYS

Money-Saving filters use metal leaves, precoated with an asbestos-diatomaceous earth slurry, to clarify sugar juice.

Filters "thick juice" through Monel leaves . . . saves $100 per day

In a 190-day beet sugar campaign at its Santa Ana, California plant, Holly Sugar Corporation saved $19,000 last year in filtering sugar "thick juice".

They did it by switching from plate-and-frame filter presses to wholly enclosed, "self-sluicing" leaf filters built by United States Filter Company, El Monte, California.

Monel* nickel-copper alloy internals do the work

In each filter there are 22 Monel alloy leaves, each made of five wire screens stretched between a cast hub and a specially formed U-channel rim. A pre-coat is laid on automatically in 10-minutes. After the run, it is jetted off with the cake in 4 minutes.

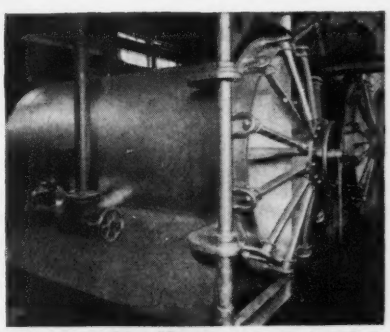
Internal parts are not only exposed to corrosion by the hot juice, but also must be designed to permit use of acid to remove scale without harm. Of course, the juice must be protected from any possible contamination by metallic corrosion products. And the screens must not deform under pressure.

Monel nickel-copper alloy provides the needed combination of high corrosion resistance and strength.

Many other sugar and salt producers find Monel alloy essential in equipment to produce high purity product at low cost. If you would like to investigate potential uses in your process, Inco's Corrosion Engineering Section will be glad to help with available data and information.

*Registered Trademark

The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.



Battery of jet filters with Monel nickel-copper alloy internals provides continuous flow of filtrate in what amounts to almost a "push-button" operation. Direct savings, $19,000. Other benefits include: (1) higher quality, more uniform filtrate; (2) ⅔ reduction in square feet of filter area required; (3) faster filtering; (4) the ability to handle higher-density juice.

Monel... *for minimum maintenance*

NEW PRODUCTS

(Continued from Page 100)

finish for aluminum is now being offered on its industrial products by Aluminum Company of America. The finish is a joint development of Alcoa and American Chemical Paint Co., Ambler, Pa. Besides forming a soft green color integral with the metal surface the coating is said to increase aluminum's resistance to corrosion from salt spray and industrial fumes.

•

Boron Trichloride production of Stauffer Chemical Company at Niagara Falls will be increased tenfold. A new process will be used.

Super 5300, latest among Unichrome plastisol coatings, is described in a 4-page illustrated folder available from Metal and Thermit Corp., Rahway, N. J. The new coating, which can be sprayed in thicknesses up to 60 mils in a single application and even to cold vertical surfaces, is reported to protect metals against a wide range of acids, alkalis, salt solutions and complex chemical corrosives.

•

Chemical Linings, Inc. has purchased a building at 156 Stone St., Watertown, N. Y. T. E. Detcher is president.

•

Industrafix, a rapid fixer for film and paper manufactured by Edwal Scientific Products Co., Inc., 420 West 111th St., Chicago is reported to be much less corrosive than some other preparations for the same purpose.

•

List "D" of Available Publications on Ductile Iron and a folder "Helpful Publications for Production Men, Design Engineers, Metallurgists, Metal Users," are available from Reader Service Section, The International Nickel Co. Inc., 67 Wall St., New York City.

•

Air-Cooled Selenium rectifiers marketed by Corrosion Services, Inc., P. O. Box 7343, Tulsa, Okla. have several new features, including a down-opening door, better ventilation for the rectifier stacks, better accessibility of parts and cable opening at the rear.

•

H-400 Scale Solvent, a product of Bull & Roberts, Inc., 117 Liberty St., New York 6, N. Y. will permit a ship's crew to remove calcium carbonate and magnesium hydrate scales from marine heat exchanger surfaces by converting it to soluble salts. Iron oxide scale also is broken up, manufacturers claim. The product is said to be non-fuming, free from irritating odors and not to produce corrosive gases.

•

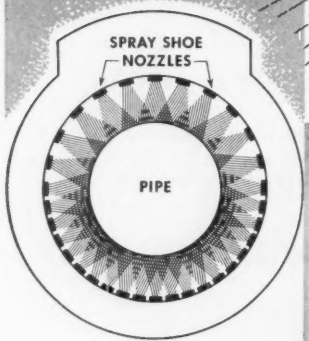
Protection With Parlon, an illustrated 20-page and cover brochure describes use of Parlon based paints in numerous types of maintenance work.

•

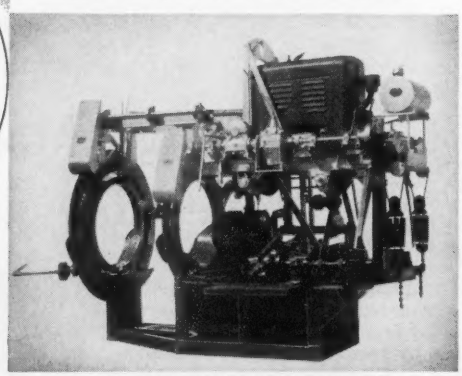
Aluminum Cylinders, crankcase, cylinder heads, covers and timing gear housing help to make the 200-pound V-4 engine developed by American Motors Corp. develop 62 horsepower. AMC sees the engine as suited to powering airborne military vehicles, for use in small automobiles and to operate pumps and generators. The valve-in-head arrangement has a 7.5 to 1 compression ratio.

A SPRAY SHOE Should SPRAY!

Perrault Coating & Wrapping Machines Have Exclusive NOZZLE-FITTED SPRAY SHOE



Spray shoe cross section shows how spray nozzles give DOUBLE dope coverage on pipe top, TRIPLE coverage on pipe bottom . . . Insurance for a better coating job.



DOUBLE-COAT, DOUBLE-WRAP MACHINE

PERRAULT COATING AND WRAPPING MACHINES for large pipe sizes are more dependable. They have less downtime because, when compared to the industry, they are designed with: More power, heavier transmissions, bigger clutches, stronger speed reducers, greater pumping capacity, full-width rubber crawlers. Even with these better components Perrault units are lighter in weight. Other models available for all pipe sizes; any coat and wrap combination. Call Perrault for complete details.

ALSO CARRIED IN STOCK:
Pneumatic Inside Line-up Clamps — sizes 20 to 36 in. Cleaning and Priming Machines — line traveling or stationary. Glass Pipe Wrap, Asbestos Felt Wrap, Kraft Wrap, and Rock Shield. Tar-Heating Kettles, Burners, Patch Pots and Accessories.
Pneumatic-Tired Lowering-In Cradles, Adjustable Pipe Cradles, Five-roller Cradles, Tongs, Hooks, Blocks, Belts, Slings, Line-up Clamps, Hand Tools, Supplies and Equipment of every sort.

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MEN in the NEWS

R. A. Colton, Federated Metals Div., American Smelting & Ref. Co. has been elected chairman of the Metropolitan Chapter of the American Foundryman's Society.

•

Leo M. Monroe has been appointed manager of Industrial equipment sales for the Brush Electronics Co., Cleveland.

•

Robert Weldon, senior project engineer, Missile Development Division, North American Aviation, Inc., Downey, Cal. is general manager of the 1956 annual Protective Packaging and Materials Handling Competition to be held in St. Louis October 22-25.

•

John S. Pettibone, for several years an assistant technical secretary of American Society for Testing Materials has joined the research laboratory of The International Nickel Co., Inc., at Bayonne, N. J. He has held several offices in NACE's Philadelphia Section.

•

John L. Goforth has been elected sales manager of Pipecote Service Corp., 3920 South Peoria, Tulsa 5, Okla.

•

George E. Brumbach has been appointed chief metallurgist for Carpenter Steel Co., Reading, Pa. He has been with Carpenter since 1933 and fills the

(Continued on Page 103)

MEN in the NEWS

(Continued from Page 102)

place vacated by Dr. Carl B. Post, now vice president and technical director.

•

Robert Nordin, 3600 Griggs Road, Houston is All-State Welding Alloys Co., Inc. regional manager for Louisiana, Mississippi, East Texas, Southern Alabama and the Florida Panhandle.

•

William J. Ryan and **Morris L. Rosenfeldt** have been appointed vice-presidents of Water Service Laboratories, Inc., 423 West 126th St., New York, N. Y. Both joined the company in 1933.

•

Frank Grisak, formerly senior nuclear engineer with Consolidated Vultee Aircraft Corp. in charge of preliminary design of the atomic reactor now being tested aboard a B-36 by that company is now nuclear specialist to the engineering department of Temco Aircraft Corp., Dallas.

•

Robert W. Liddell has been appointed assistant research manager for Calgon, Inc. and Hall Laboratories, Inc. subsidiaries of the Hagan Corp., 324 Fourth Ave., Pittsburgh 30, Pa. He joined Calgon in 1935 after graduating from University of Pittsburgh.

•

Harold W. Rice has been appointed director of the West Coast Research and Development Laboratory of Robertshaw-Fulton Controls Co., at Los Angeles.

•

R. M. Smith has joined the engineering staff of Corrosion Services, Inc., Tulsa. He will help design cathodic protection systems for underground structures.

•

Hallberg Hanson has been named plant manager of the new Polyken industrial tape plant now under construction at Franklin, Ky. He has been with The Kendall Co. since 1946.

•

Carl D. Thomas has been appointed supervisor of the Maintenance Engineering Section of the Engineering Dept., Chemical Division, Pittsburgh Coke and Chemical Co., Pittsburgh, Pa.

•

Harry W. Buchanan III has been named salesmanager of chemicals, metals and plating products; **Henry Mahlstedt** products manager for plating products; **George Betz**, products manager for chemicals and metals; **Ronald R. Meserve**, product manager for coatings of Metal and Thermit Corp. **Donald R. Oakley** has been transferred from assistant production manager to technical adviser to the president of the firm.

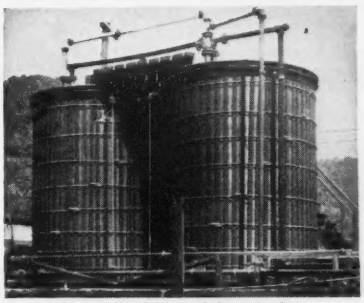
•

Robert M. Burns, Summit, N. J. has been selected to receive the Edward Goodrich Acheson Gold Medal and Prize of The Electrochemical Society, Inc. Presentation will be made at a dinner October 2 when Dr. Burns will deliver the Acheson Medal Address at the society's 110th meeting in Cleveland. Dr. Burns formerly was chemical director of Bell Telephone Laboratories and now is scientific adviser to Stanford Research Institute and to the Sprague Electric Co.

HAVEG® News

Wherever CORROSION RESISTANCE is a Factor

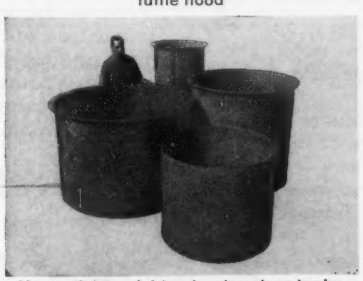
IF CORROSION IS THE PROBLEM HAVEG PLASTICS ARE THE ANSWER!



Haveg storage tank installation

Haveg corrosion resistant valves

Large Haveg polyester glass self-supporting fume hood



Haveg light weight polyester glass tanks

Rugged strength and durability . . . exceptional resistance to corrosion . . . longer, trouble-free service at process temperatures as high as 350°F.—you get them all at bonus savings in installation time, material, and maintenance costs with Haveg plastic equipment.

PROCESS PIPE, TANKS, TOWERS, FUME REMOVAL SYSTEMS, DISTILLATION COLUMNS, FILTER PRESS PLATES—wherever industrial equipment is required to handle corrosive materials or atmospheres—Haveg corrosion resistant plastics have solved the problem at leading process plants. In addition to equipment a wide selection of Haveg resin cements offer required chemical resistant properties for extensive use as mortar in chemical brick and tile flooring, equipment lining, etc.

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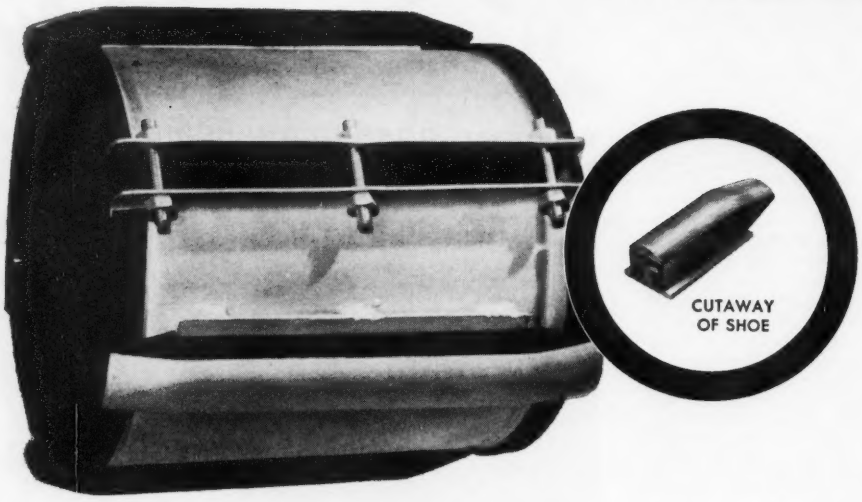

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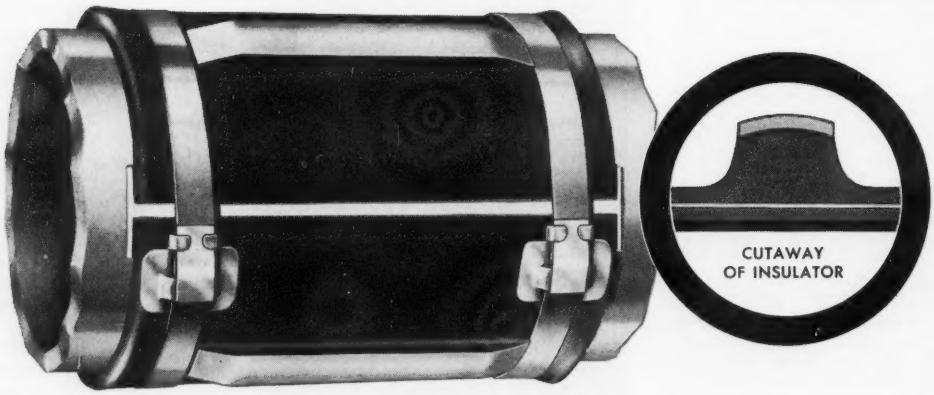

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CORROSION ABSTRACTS

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Vol. 12 September, 1956 No. 9

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1. GENERAL

1.2 Importance

1.2.2

Reducing the Cost of Corrosion in Canada. H. P. GODARD. *Chemistry Can.*, 7, No. 9, 35-38 (1955) Sept.

Reviews briefly the common forms of corrosion, general principles of corrosion control and sources of information on corrosion and its prevention (National Association of Corrosion Engineers, Technical Information Service-National Research Council in Ottawa, textbooks and journals). Estimated annual cost of corrosion in Canada is $500 million.—INCO. 10553

1.7 Organized Studies of Corrosion

1.7.1

Attention to Corrosion in the U.S.A. F. L. LAQUE. Paper before Soc. Chem. Ind., Corrosion Group Spring Lecture, London, March 30, 1955. *Chemistry & Industry*, No. 33, 1016-1025 (1955) Aug. 13.

Traces history and reviews purpose and activities of several technical groups in the United States that deal with corrosion to a major extent. These include the Inter-Society Corrosion Committee, American Society for Testing Materials, Electrochemical Society, National Association of Corrosion Engineers, and National Bureau of Standards. Corrosion work in the Armed Services is carried on by the Naval Research Laboratory, Naval Engineering Experimentation Station, the National Advisory Committee for Aeronautics at Wright Air Development Centre, Signal Corps at Fort Monmouth and Ordnance Corps at Rock Island Arsenal. Present projects at universities and elsewhere sponsored by the Office of Naval Research are reviewed. Results of recent survey of corrosion education in engineering schools are reported. Map shows ASTM atmospheric corrosion test sites. Appendix lists organizations represented on the Inter-Society Corrosion Committee, ASTM committees represented on Advisory Committee on Corrosion and the technical committees of the NACE. 23 references.—INCO. 10437

1.7.1, 1.6

Chemistry Research, 1954. Chemical Research Laboratory, Dept. Sci. and Ind. Res. Pamphlet, 1955, 71 pp. Available from: H. M. Stationery Office, London.

Reports the work of the Chemical Research Laboratory at Teddington in 1954. Includes corrosion (pp. 10-20; immersed, underground, microbiological and atmospheric corrosion); selenium in waste products and methods of recovery (pp. 21-25); analytical methods (pp. 26-29; paper chromatography; ion-exchange; physical methods).—BNF 10868

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AWWA—Journal, American Water Works Association, Amer. Water Works Assoc., 521 Fifth Ave., New York 17, N. Y.
BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.
BTR—Battelle Technical Review, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.
BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.
CBEC—Centre Belge d'Etude de la Corrosion (CEBELCOR), 17 re des Drapiers, Brussels, Belgium.
CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.
EL—Electroplating. 83/85 Udney Park Road, Teddington, Middlesex, England.
EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.
GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.
IIM—Transactions, The Indian Institute of Metals, 23-B, Notaji Subhas Road, P. O. Box 737, Calcutta, India.
INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.
IP—Institute of Petroleum. 26 Portland Place, London W#1, England.
JSPS—Japan Society for the Promotion of Science, Address: Mr. Hayata Shigeno, Secretary, Committee of Preventing Corrosion, c/o Government Chemical Industrial Research Institute, 1-Chrome Nakameguro, Meguroku, Tokyo, Japan.
MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.
MI—Metallurgia Italiana, Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.
MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.
NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.
NBS—National Bureau of Standards, Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.
NSA—Nuclear Science Abstracts. United States Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.
PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.
RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.
RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.
SE—Stahl Und Eisen, Verlag Stahleisen, M. B. H., Dusseldorf, August-Thysen Str. 1. Postscheck Koln 4110, (22a) Dusseldorf, Germany.
TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.
UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.
ZDA—Zinc Development Association. 34 Berkeley Square, London W.1.

1.7.2

Field Facilities for Environment Research of the Naval Research Laboratory (Interim Report). ALLEN L. ALEXANDER AND B. W. FORGESON. Naval Research Lab., Washington, D. C., Rept. 4557 (Project Noc. NR603-020, NE120-901-4 and NE111-273), May 24, 1955, 43 pp.

For its tropical studies the Naval Research Laboratory operates the Tropical Exposure Site and the Corrosion Laboratory in the Panama Canal Zone. The Corrosion Laboratory is maintained with cooperation of the Panama Canal Company and the Engineer Research and Development Laboratories, Fort Belvoir, Virginia. The facilities include a chemical laboratory, physical testing laboratory, mycology laboratory and auxiliary equipment such as shops, photographic darkroom and extensive protected areas for field exposures. The latter consists of piers for fresh water, sea water and alternate sea water-air exposures. Atmospheric racks are located in salt laden and clear atmospheres and facilities are available for several types of jungle exposure. These tropical testing facilities are available to other government agencies and/or their contractors under most circumstances. (auth)—NSA. 10691

2. TESTING

2.1 General

2.1.1, 5.1

Corrosion and Corrosion Protection. (In German.) H. MOHLER. *Schweiz, Archiv angew. Wiss. u. Tech.* **21**, No. 6, 204-206 (1955) June.

Statistical analysis of corrosion damage on different materials, and preventive methods. 6 references.—BTR. 10590

2.2 On Location Tests

2.2.2, 5.4.5, 6.4.2, 4.2.4

Atmospheric Corrosion of Aluminum Alloys in a Large Chemical Factory and Their Protection by Painting. W. D. CLARK. *J. Inst. Metals*, **84**, Pt. 2, 33-41 (1955) October.

Relative merits of 18 paint systems on 1100 specimens of five aluminum alloys in different conditions of heat treatment and on a few mild steel specimens were determined at four sites in a large chemical factory for four years. The aluminum-magnesium, aluminum-magnesium-silicon and aluminum-manganese alloys and 99.5 percent aluminum showed so little difference in corrosion resistance that this does not appear to be an important factor in choosing among these alloys for the environments concerned; an alloy with 4 percent copper was less satisfactory. An estimated life of seven years for bare roofing sheet under the most unfavorable conditions appears probable, as against two years for bare galvanized steel. Aluminum is much superior to steel as a base for paint. In areas where steel requires repainting annually, if not more often, painted aluminum alloys show little deterioration after four years. While zinc chromate is preferred as a primer, the cover coat is relatively unimportant and may be selected on a basis of cost and aesthetic appeal.—INCO. 10725

2.2.3, 4.2.5, 7.7, 8.5.3

Corrosion of Cable Armors in Paper Mills. J. MULVEY AND J. F. QUINLAN. *Tappi*, **38**, No. 7, 403-408 (1955) July.

To determine which metals are suitable for cable armor, there were exposed small samples of 13 different metals and alloys (including four types of aluminum, three each of stainless steel and bronze, two of nickel and one of Monel) to typically corrosive atmospheres in two paper mills. One mill makes paper by the sulfate and the other by the sulfite process. Samples were cleaned and weighed at periodic intervals to determine degree of damage as function of exposure times. Test results indicate that aluminum is a good choice for cable armor in the locations tested. Degree of corrosion with aluminum was comparable to that of stainless steel, but pitting was considerably less. Since the cost of aluminum is less, it is an economical choice. Incidental confirmation of test data exists in the successful use of aluminum alloy window sashes, hand rails and stair treads in one eastern mill. For applications in locations with very heavy alkali or chlorine contamination use of a polyvinyl chloride outer jacket over the armor is considered.—INCO. 10607

2.2.4

Outside Plant Field Trials. B. J. HENDERSON. *Bell Labs. Record*, **33**, No. 7, 251-255 (1955) July.

New unit of outside plant equipment is first given preliminary tests in lab, then brought to an advanced state of development at an outdoor test plot. Finally, unit is evaluated in a field trial. Conditions to which equipment is subjected include heavy rains, high humidity, salt spray, industrial fumes and gases and corrosive soils. Illustration shows samples of strand, lashing wire

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and cable sheathing at exposure test plot at Kure Beach, N.C.—INCO. 10371

2.2.8, 2.3.4, 8.4.3, 5.8.2

Correlation of the Results Obtained with Corrosion Inhibitors in the Laboratory and in the Field. G. E. PURDY AND WILLIAM J. RIES. *Corrosion*, **12**, No. 1, 17t-22t (1956) Jan.

One of the responsibilities of the oil field corrosion engineer is to correlate laboratory and field test data. With this in mind the principal factors which influence internal corrosion in oil wells (factors which the corrosion engineer must consider) are reviewed here.

A laboratory corrosion test method is discussed. Corrosion rate data obtained in the laboratory with three West Texas crude oil and brine systems and the corrosion inhibition obtained in these systems with two organic inhibitors are analyzed and compared. Field corrosion test data for the same three fields are presented. The correlation of laboratory and field test data is discussed in relation to the many variables encountered.

It is concluded that the evaluation of the use of inhibitors in some cases may be difficult and may require considerable experience and judgment on the part of the corrosion engineer. 10577

2.3 Laboratory Methods and Tests

2.3.2

Acid Contamination as a Source of Error in Boiling Nitric Acid Test for Corrosion-Resistant Steels. ROBERT J. BENDURE. *ASTM Bulletin*, No. 207, 76-77 (1955) July.

High and erratic penetration rates were obtained when the testing area inadvertently contained hydrofluoric acid fumes. Tables.—BTR. 10486

2.3.2

Short-Time-Tests in a New Test-Chamber for Corrosion. (In German.) W. HESS. *Werkstoffe u. Korrosion*, **6**, No. 7, 325-328 (1955) July.

Describes apparatus which produces a fine, homogeneous fog; advantages and applications. Photographs, tables, diagram. —BTR. 10384

2.3.2, 2.3.7, 5.3.2

A Rust-Resistance Test for Tinplate. S. C. BRITTON AND D. G. MICHAEL. *Sheet Metal Inds.*, **32**, No. 340, 576-580 (1955) August.

Liability of tinplate samples to rusting by condensed atmospheric moisture may be compared by exposing them for 24 hours over a solution of sulfur dioxide. If samples are freed beforehand from surface films, as by cathodic cleaning, the same procedure produces clearly visible rust spots at all pores in the coating and thus provides a porosity test which is more simple and reliable than the hot-water test. Photographs compare specimens exposed to sulfur dioxide solution and those exposed to condensed atmospheric moisture.—INCO. 10477

2.3.2, 3.7.3, 6.2.5

Methods of Determining the Total Corrosion Resistance of Welded Joints of Stainless Steel in Boiling Nitric Acid. (In Russian.) B. I. MEDOVAR AND N. A. LANGER. *Zavodskaia Laboratoriia*, **21**, No. 8, 941-944 (1955) Aug.

Micro-structure revealed by electrolytic etching in a solution of oxalic acid. Diagrams, table, micrographs. 10 references.—BTR. 10892

2.3.2, 5.3.2

Progress Report on Accelerated Corrosion Tests for the Performance of Plated Coatings. W. L. PINNER. *Plating*, **42**, 1039-1043 (1955) August.

Report on work to furnish the metal finishing industry with a valid test which is reproducible and will predict service behavior of plated coatings. Photographs. 2 references.—BTR. 10600

2.3.4, 3.2.2

Resistance of Tubular Materials to Sulphide-Corrosion Cracking. J. P. FRASER AND R. S. TRESEDER. *Trans. Am. Soc. Mech. Engrs.*, **77**, 817-822; disc., 822-825 (1955) August.

Laboratory test procedure for rating alloys as to their resistance to sulfide-corrosion cracking. Tables, photographs. 7 references.—BTR. 10524

2.3.4, 4.4.7

Aviation Lube Tests a Problem? F. G. HESS, F. E. LANDIS AND A. R. RESCORLA. *Petroleum Processing*, **10**, No. 9, 1374-1377 (1955) Sept.

Laboratory bench method for predicting deposit forming and corrosion characteristics of aviation lubricating oils is described. Test method consists essentially of oxidizing an oil at 300F and subjecting it to temperatures of 550-900 F. Corrosiveness of bronze test pieces was determined in both liquid and vapor

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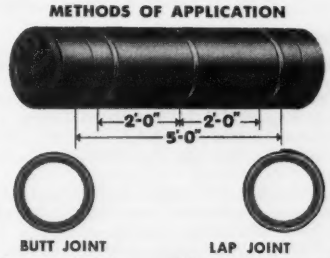

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phase. Laboratory results are compared with actual flight test results. Illustrations, tables.—INCO. 10372

2.3.6, 2.3.7, 3.5.9

A Microscope Hot Stage. H. A. Saller, R. F. Dickerson and R. J. Carlson. *Metal Progress,* **67,** No. 5, 105-108 (1955) May.

Compact unit for studying thermal-etching, progression of fatigue cracks, recrystallization and other structural changes in metals at temperatures up to 1800F is described. Four principal component sections are vacuum furnace, optical system, cold trap and vacuum pumping system. Series of photomicrographs showing thermal-etching characteristics of SAE 1008 steel is included. Microstructure before, during and after heating to 1645F is shown.—INCO. 10391

2.3.6, 6.3.10, 2.3.9

Method of Anodic Etching Particularly Suitable for Electron-Micrographic Examination of Age-Hardening Heat-Resisting Alloys of the 80/20 Nickel-Chromium Type. Y. Baillie and P. Gilles. *Compt. Rend.,* **240,** 1430-1432 (1955) March 28.

Describes use of solution containing 5 percent hydrofluoric acid, 1.85 percent propanol, 10 percent glycerol for etching of materials such as the Nimonic alloys and Inconel X.—INCO. 10700

2.3.7

Corrosion. Mars G. Fontana. *Ind. & Eng. Chem.,* **47,** No. 6, 91A-92A (1955) June.

Several procedures are outlined for stress-corrosion tests in metals. Types of corrosion specimens and methods of stressing the specimens are described. —NSA. 10526

2.3.7

Metals: Their Use and Testing. L. E. Benson. *Metropolitan-Vickers Gazette,* **26,** No. 431, 184-194 (1955) June.

A paper presented to the Manchester Association of Engineers, October 15, 1954; a few recent developments of interest concerning applications and testing: physical and mechanical properties of titanium; sintered alloys (tungsten, molybdenum, tantalum and tungsten carbide bonded with cobalt); solidification of ingots; magnetic and ultrasonic testing; manufacture, inspection and testing of castings and tubes. (70/30 copper-nickel, aluminum, brass) and stress-corrosion cracking tests.—BNF. 10469

2.3.7

Reproducibility of Wohler-Type Fatigue Tests. J. Clayton-Cave, R. J. Taylor and E. Ineson. Brit. Iron Steel Res. Assoc. Paper MG/M/64/55 of Fatigue & Inclusions Comm. of Metall. Div. *J. Iron Steel Inst.,* **180,** Pt. 2, 161-169 (1955) June.

Variabilities of fatigue test results obtained from individual testing machines, a battery of twelve testing machines of identical design and a number of testing machines of similar design in different laboratories were studied in an experiment permitting statistical planning and analysis of results. Fatigue data provided by a batch of machines in one laboratory are more variable than those provided by an individual machine. An increase in variability of 37 percent was found when testing a 0.24 percent carbon steel at ± 17.5 tons/sq. in. with twelve testing machines. Data provided by more than one laboratory are even more variable. Influence of small changes in design of test pieces on the variability of test results was studied and found insigificant while a common critical section is maintained. 9 references.—INCO. 10537

2.3.7

Elevated-Temperature Testing Procedures. Part I. Continuous Recording of Time Deformation Readings During Creep-Rupture Testing at Temperatures up to 1200F. W. H. Rector and C. A. Townsley. U. S. Wright Air Development Center, Tech Rept. No. 54-214-Pt. 1, February, 1955, 9 pp.

New method of recording deformation during creep-rupture testing up to 1200F. Method has advantages of obtaining a continuous time-deformation record up to failure, compared to intermittent readings by former manual method and being completely automatic. Various alloy sheet materials and metal-to-metal abhesive bonded specimens have been tested with this procedure. Strain gage, recording equipment and electronic control are described. Illustrations.—INCO. 10623

2.3.7, 2.4.2

Method for Corrosion-Fatigue Testing. L. A. Glikman and L. A. Suprun. *Zavodskaya Laboratoriya* (Factory Laboratory), **21,** No. 4, 464-466 (1955).

Description of a corrosion-fatigue testing machine operating at a cycle frequency of 2860 rpm, with the specimen immersed in the corrosive medium. Design of machine and shape and dimensions of specimens are illustrated. Testing procedure, test results obtained on a plain carbon structural steel and gray iron in air, river water and 3 percent sodium chloride solution and effect of cycle frequency and corrosive medium upon results are discussed.—INCO. 10774

2.3.7, 2.4.2

Examination of Microstructures Under Varying Stress. R. A. Flinn and P. K. Trojan. *Metal Progress,* **68,** No. 1, 88-89 (1955) July.

Bend test apparatus is described that permits continuous microscopic examination of metal specimens while they are being loaded to fracture. Micrographs of nodular cast iron during bend test show distortion of graphite on both tension and compression sides of specimen as loading is increased. Photomicrographs.—INCO. 10638

2.3.7, 3.5.9

The Conductometric Method Applied to the High Temperature Oxidation of Iron. George C. Fryburg. *Corrosion,* **12,** No. 2, 84t-86t (1956) February.

The conductometric method is used to study the oxidation of pure iron in the region of 600C. Iron ribbons of known thickness were used in the tests and the conductance of the central portion of the specimens measured by the potentiometer method. A constant current of 50 ma, small enough to prevent heating even in vacuum, was used. It was found that the conductivity method gives a true measure of the thickness of iron oxidized and yields results that are in agreement with those obtained by the gravimetric method.

An analytical method of measuring the amount of unoxidized iron remaining in specimens is described briefly. 10703

2.3.7, 3.5.9, 3.5.8

Effect of Strain on the Oxidation of Nickel-Chromium Heater Alloys. E. A. Gulbransen and K. F. Andrew. Paper before Am. Soc. Testing Materials Symp. on Basic Effects of Environment on the Strength, Scaling and Embrittlement of Metals at High Temperatures, Cincinnati, February 2, 1955. ASTM Special Technical Publication No. 171, 1955, 35-46; disc. 47-48.

To give a more complete picture of physical and chemical factors involved in high-temperature oxidation, a new test method was developed called "strain-oxidation." In this test the metal is oxidized a given amount, strained 1-4 percent and then reoxidized. Rates of oxidation before and after strain are carefull measured. Five nickel-chromium heater alloys of varying silicon and manganese compositions are studied. Two kinds of damage in the oxide film are found as a result of strain. The first is shown by a rapid rate of oxidation on first reoxidizing the metal while the second involves a long-term effect. Results on the high-silicon alloys show that strain has only a minor effect on the rate of oxidation. The strain-oxidation tests show good correlation with the ASTM useful life tests and suggest that the resistance of the alloy to stress during oxidation is relatively more important than the rate of oxidation at a given temperature. 9 references.—INCO. 10819

2.3.7, 5.4.5

Preliminary Evaluation of Protective Coating Systems. R. W. Flournoy. *Corrosion,* **11,** No. 7, 289t-290t (1955) July.

Summarizes preliminary laboratory tests for selection of protective coatings. Tests are based on certain physical characteristics which are required for coatings formulated from organic materials with high electrical resistance. Coatings are tested on steel panels. Thickness is measured with a magnetic circuit tester (Elcometer) or micrometer. Flaws and holidays in coatings are detected by electrical resistance measurements. Flexibility, adhesion and hardness tests and basic chemical tests are reviewed. Minimum acceptable values are given.—INCO. 10637

3. CHARACTERISTIC CORROSION PHENOMENA

3.5 Physical and Mechanical Effects

3.5.8

Combination of Methods for Increasing Corrosion-Fatigue Resistance of Steel. (In Russian.) A. V. Riabchenkov and V. F. Abramova. *Vestnik Mashinostroeniia,* **35,** No. 7, 54-57 (1955) Jul.

Investigation of surface hardening followed by electrolytic chromium or zinc coating and surface hardening in combination with cathodic protection. Tables, graphs, diagrams, photograph. 9 references.—BTR. 10630

3.5.3

Recent Investigations of the Mechanics of Cavitation and Cavitation Damage. R. T. Knapp. Paper before Am. Soc. Mech. Engrs., Ann. Mtg., New York, November 28-December 3, 1954. *Trans. ASME,* **77,** No. 7, 1045-1054 (1955) Oct.

Describes water-tunnel experiments to study mechanics of fixed-type cavitation and mechanism through which this type

causes material damage. High-speed motion pictures were used to observe the mechanics. Pitting rate of soft 2S-F aluminum was measured to determine damage pattern. Information was obtained on the frequency and intensity of damaging blows, distribution of damage in relation to area covered by cavitation and variation of intensity with velocity. Graphs, photomicrographs, 18 references. —INCO. 10843

3.5.3, 2.3.7

Cavitation Attack in Ultrasonic Equipment. L. A. PETERMANN. Gulton Industries. *Product Eng.*, **26,** No. 9, 173-178 (1955) September.

Phenomena of ultrasonic cavitation, characteristics of ceramic transducers, test method devised to study cavitation damage and methods for protecting transducer electrodets are discussed.—INCO. 10840

3.5.5, 3.5.9

On the Diffusion of Oxygen Through Solid Iron. J. L. MEIJERING. *Acta Metallurgica*, **3,** No. 2, 190-198 (1955) March.

Internal oxidation of three iron alloys, 0.97 percent aluminum-balance iron, 0.9 percent aluminum-30 percent nickel-balance iron, 0.50 percent aluminum, 5 percent tin-balance iron, showed, at least at 1200C, no trace of intergranular preference. Normal interstitial diffusion of oxygen through the iron lattice must be assumed. Approximate values of permeability of oxygen in iron at different temperatures are calculated from the sub-scale thickness. Permeabilities of iron, nickel, copper and silver for oxygen at 85 percent of their absolute melting temperatures are of the same order of magnitude. Discrepancies in the solubilities of oxygen in solid iron found by different authors are discussed. Photomicrographs and 27 references.—INCO. 10557

3.6 Electrochemical Effects

3.6.6, 6.4.2, 2.2.2, 6.2.3, 5.3.2

Metal Coatings on Steel in Contact with Aluminum Alloys: Some Comparative Corrosion Tests. S. C. BRITTON AND R. W. DE V. STACPOOLE. *Metallurgia*, **52,** No. 310, 64-70 (1955) August.

Steel screws and nuts coated with zinc, cadmium and tin-zinc alloy were exposed in contact with five aluminum alloys to suburban, industrial and marine atmospheres, to intermittent immersion in the sea and to salt spray in the laboratory. For long term protection of steel and aluminum, tin-zinc was the most useful general purpose coating on steel: measurement of current flow between the two metals gave useful results in predicting the performance of the bimetallic couples.—BNF. 10709

3.7 Metallurgical Effects

3.7.2, 3.7.3, 6.2.3

Some Observations on Temper-Brittleness. L. COLOMBIER. Paper before Journees Metallurgiques d'Automne, October, 1954. *Rev. met.*, **52,** 643-656; disc., 656-657 (1955) August.

Tests on steels produced under conditions reproducible in industry. Data on toughness as a function of temperature include influence of carbon, silicon (in steels containing varying amounts of silicon), nickel, (six steels with 0.11-4.65 percent nickel), simultaneous effects of combined silicon and nickel (0.25-2.2 silicon with 2.52-4.54 percent nickel), effects of chromium (critical content cited as 2 percent), and simultaneous effects of combined chromium and nickel (2.54-4.48 nickel, 0.76-3.28 percent chromium). Amounts of silicon and chromium which tend to produce temper-brittleness decrease in ratio with rising nickel content.—INCO. 10723

3.7.2, 3.8.2

Electrochemical Theory of Corrosion and Ways of Increasing the Corrosion Resistance of Alloys. (In Russian.) N. D. TOMASHOV. *Uspekhi Khimii*, **24,** No. 4, 453-470 (1955).

Effect of structural heterogeneity; circumstances under which passive state of metal appears; corrosion resistance increased by alloying with cathodic additions. Graphs, diagrams, tables. 41 references.—BTR. 10362

3.7.3

New Aluminum-Ceramic Bond Produces Hermetic Seal. G. W. HUME. *Materials and Methods*, **41,** No. 4, 110-111 (1955) April.

A satisfactory high temperature hermetric seal between aluminum and ceramics may be produced by "tinning" the ceramic. It is painted with zirconium hydride powder, on which a washer of, e.g., pure silver is placed: on heating zirconium is formed on the ceramic and alloys with the silver, forming a "tinned" surface on to which aluminum may be melted.—BNF. 10431

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3.7.3

Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes. American Welding Society and American Society for Testing Materials. A.W.S. Designation A5.4-55T, A.S.T.M. Designation A298-55T, 1955, 13 pp. Available from: A.S.T.M., 1916 Race St., Philadelphia 3, Pennsylvania.

Specification for electrodes yielding weld metal containing over 4 percent chromium, not more than 50 percent nickel. Covers composition, tensile test, fillet-weld test, dimensions, etc. An appendix gives a guide to the AWS-ASTM classification of stainless steel electrodes.—BNF. 10718

3.7.3

How and Where to Use Spot Welding. *Industry & Welding,* **28,** No. 6, 71-74, 76 (1955) June.

Step-by-step instructions on how and where to use spot welding are given. Size of electrode and weld pressure—two basic factors in spot welding are discussed and timing cycle is shown graphically. Special procedures for welding steel and stainless steel are considered. Short time is needed because of high resistance; carbide precipitation, which can cause corrosion, is apparent with a long weld time.—INCO. 10433

3.7.3, 1.4

Welding and Brazing: A Bibliography of Unclassified Report Literature. Gifford A. Young, compiler. Technical Information Service, Atomic Energy Commission, Rept. No. TID-3059, January, 1955, 46 pp.

A selection of 226 unclassified reports held by the Technical Information Service as of October 1, 1954 and containing information on the welding and brazing of materials of interest to the Atomic Energy Commission, such as aluminum, beryllium, hafnium, molybdenum, tantalum, thorium, titanium, uranium, zirconium, stainless steels, heat exchangers and pressure vessels has been annotated. Reports on corrosion and other properties of welded and brazed materials also have been abstracted. Author, subject and report number indexes are included. (auth).—NSA. 10403

3.7.3, 1.6

Development of Brazing Alloys for Joining Heat Resistant Alloys. Forbes M. Miller, Homer S. Gonser and Robert L. Peaslee. Wall Colmonoy Corp. U. S. Wright Air Development Center, Tech. Rept. No. 55-213, March, 1955, 70 pp.

Fifteen different alloy systems were tested and studied for brazing characteristics and chemical and physical properties. These alloys were nickel-base binary and ternary systems containing such metals and metalloids as phosphorus, silicon, chromium, manganese, molybdenum, tungsten and iron. The nickel-phosphorus-chromium system and nickel-phosphorus-silicon system showed the best properties of the phosphorus-bearing alloys. The nickel-silicon-manganese system showed the best properties of the silicon-bearing alloys. Of the alloys studied the silicon-bearing alloys in general are higher melting than the phosphorus-bearing alloys. Studies also showed the phosphorus and manganese contributed the most toward improving the flow and wetting properties of the alloys, while silicon and chromium contributed the most toward improving the oxidation resistance and strength properties of the alloys. (auth).—NSA. 10561

3.7.3, 3.2.2

Elimination of Cracking in Carburized Nickel-Chromium Steel Parts. A. M. Nakhimov. *Vestnik Mashinostroeniya,* **35,** No. 3, 74-75 (1955); Chem. Abs., **49,** 10818 (1955) Aug. 25.

Cracking (after cooling to room temperature in 10-15 hr.) can be prevented by tempering at 650C before cooling to 150C. Relation between cracking of carburized steels and shape of dilatometric curves is discussed. Cracking is almost absent when rapid decomposition of austenite of uncarburized steel occurs at 550-650, and very pronounced when it starts to decompose at 440. Dilatometric curves are given.—INCO. 10829

3.7.3, 3.2.2, 6.2.3

Effect of Pretreatment of Martensite on Subsequent Graphitization at 1200F. G. V. Smith, E. J. Dulis and B. W. Royle. *Welding J.,* **34,** No. 8, 374s-378s (1955) August.

A martensitic eutectoid steel (0.02 percent nickel) formed many more nodules of graphite at 1200F if first exposed at 800-1000F, suggesting a possible relation between the high susceptibility of martensite to graphitization and the translation from epsilon carbide to cementite. The steel could be completely graphitized at 1200F in 100 days and showed an unusual reaction curve such that the rate slowed markedly after five days' exposure.—INCO. 10402

3.7.3. 3.5.8

Effect of Preheating on Stress-Corrosion Cracking of Steel Weldments. E. P. DeGarmo and I. Cornet. Paper before Am. Welding Soc., National Fall Mtg., Philadelphia, October 17-21, 1955. *Welding J.,* **34,** No. 10, 472s-475s (1955) October.

Steel weldments of three low-carbon steels were immersed in an aqueous solution of 60 calcium nitrate and 3 ammonium nitrate at 225-235F in the as-welded, 400F preheat and high-temperature stress-relieved conditions. Preheating was found to be of considerable benefit in reducing stress-corrosion cracking, but not as effective as high temperature stress relieving. Cracks did not start in the welds but in heat-affected zone adjacent to the welds. Quantitative data regarding crack growth and supplementary bend test data lead to theory that cracking results from combination of stress and some type of discontinuity. Tables, graph.—INCO. 10745

3.7.3, 3.5.8

Stress-Corrosion Cracking of Welded Joints. R. N. Parkins. Paper before Inst. of Welding, N. E. Tyneside branch, February 3, 1955. *Brit. Welding J.,* **2,** No. 11, 495-501 (1955) Nov.

Stress-corrosion cracking is usually associated with welded joints because of the residual stresses that remain in structure, although development of a critical microstructure in heat-affected zone may further promote stress-corrosion. Furnace annealing at appropriate temperature is most reliable practice of avoiding stress-corrosion failures, but peening and controlled low temperature stress-relief are used for components which cannot be annealed. Photomicrographs show intercrystalline cracks in aluminum-10 magnesium alloy and transcrystalline cracks in 18-8. Graph shows relationship between stress and cracking time for 0.09 carbon steel in boiling nitrate solution. 26 references.—INCO. 10847

3.7.3, 5.9.4, 5.3.4

Selective Surface Hardening. J. L. Harris. Paper before Australian Inst. of Metals, Sydney branch. *Australasian Engr.,* **1955,** 45-52, October 7.

Deals briefly with number of methods of hardening selected surfaces: case hardening (carburizing, cyaniding, and nitriding), hard chromium plating, and heating and quenching (induction and flame hardening), and describes in detail the flame hardening method. Spot, progressive (flat progressive, spiral-band and circular-band), spin and spin-progressive methods of flame hardening are discussed. Materials suitable for flame hardening, including carbon steels, cast steels, chromium, manganese, molybdenum, vanadium and nickel alloy steels and cast irons (including nickel-molybdenum and nickel-chromium-molybdenum) are listed. General specification for a cast iron having good flame hardening properties is: 3.3 total carbon, 1.0-2.0 silicon, 1.0-2.0 nickel, 0.6-1.0 manganese and max. 0.75 chromium, molybdenum and vanadium. Equipment, costs and advantages of flame hardening are considered. Graphs, table.—INCO. 10773

3.7.3, 6.2.5

Your Stainless Welds—Are They Corrosion Resistant? Leak-Tight? A. Grodner. Continental Copper & Steel Inds. *Industry & Welding,* **28,** No. 9, 52-54, 98-99 (1955) Sept.

Four large tanks of Type 316 ELC were commissioned by the Atomic Energy Commission for storage of atomic waste products. Double butt-weld seams were made by shielded inert gas metallic arc method using Type 316 ELC consumable electrode, with argon gas on welding side and helium on interior side. Using boiling nitric acid test, deposited weld metal was acceptable only if it did not exceed corrosion rate of 0.003 inch per month for five 48 hour periods. Tanks were subjected to hydrostatic pressure and halogen vapor tests and all seams were further reinforced with ¼ inch thick Type 316 ELC bars continuously welded to tank walls to provide additional life extension factor.—INCO. 10767

3.7.3, 6.3.6, 6.4.2

Preventing Embrittlement in Copper-to-Aluminum Weld Joints. C. L. Carlson and R. M. Leedy. *Product Eng.,* **26,** No. 10, 172-173 (1955) Oct.

Embrittlement in flash-welded aluminum-copper transition joints is prevented by avoiding critical time-temperature conditions during required operating life. Joint embrittlement results from logarithmic growth of a brittle diffusion layer. Safe temperature-with-time data are presented as obtained from impact test described. Graph, photomicrographs.—INCO. 10722

3.7.3, 6.4.2

Testing and Inspection of Welds in Aluminium and Aluminium-Alloy Plate Made by the Inert-Gas Shielded Welding Process. P. Bradley. *Brit. Welding J.,* **2,** No. 10, 459-463 (1955) October.

The inert-gas-shielded welding processes have been used extensively in the fabrication of vessels from aluminum and aluminum-alloy plate. It has been found necessary to apply a strict procedure of testing and inspection of the welding when the vessels are required for use with highly corrosive liquids. The qualification test of the welders and radiographic inspection procedure are

described in detail, together with some typical defects as revealed by fracture and radiographic examination. Some results on the frequency of defects in welded vessels are given and the effectiveness of localized repairs to the weld are discussed.—ALL. 10677

3.7.3, 6.4.2

The Comparative Experiments on Tungsten-Arc-Argon Atmosphere Welding and Oxy-Acetylene Welding (First Report). TAKAKADO NAKAYAMA AND KOUSUKE OTAKA. *Lights Metals* (Japan), No. 15, 79-87 (1955) May.

This report illustrates comparative experiments of tungsten-arc-argon atmosphere welding and oxyacetylene welding on the weldability and corrosion resistance of aluminum alloys. Two experiments were carried out. 1) The weldability of plates of 52S, 56S, 0.5 percent magnesium-aluminum alloy, A51S, and 17S in thicknesses of 1.6, 3.2 and 6.3 mm are as follows: The weldability was estimatetd by tests of their tensile strength, elongation and thermal influence, produced in plates butt-welded by means of tungsten-arc-argon atmosphere and oxyacetylene flame. The results show the order of weldability as follows: 0.5 percent magnesium-aluminum alloy, 52S, 56S, A51S and 17S. The thicker the sheets and plates, the less the weldability. Tungsten-arc-argon atmosphere welding was superior to oxyacetylene welding in this test, especially for thicker plates. 2) The corrosion resistance of the plates, butt-welded by means of tungsten-arc-argon atmosphere and oxyacetylene flame of 61S, 52S, 53S, 63S, A51, AW10, 56S and Lloyd heat treatable alloy, which were made from the base metal of 99.7 percent aluminum with thickness of 1.6 mm were as follows. The corrosion tests were examined by the decrease of tensile strength of the welded plates which were immersed as long as a year in a solution containing 6 percent sodium chloride and 0.3 percent hydrogen peroxide. The results did not show any difference in respect to the method of welding. The order of corrosion resistance of the alloys is as follows: 99.7 percent aluminum, 52S, 63S, 99.3 percent aluminum, 53S, Lloyd heat treatable alloy, 56S, A51S, AW10 and 61S.—ALL. 10612

3.7.3, 7.7

Production Brazing of Aluminum-Sheathed Heating Elements. C. A. MCFADDEN. Selas Corp. of Am. *Ind. Heating*, **22**, No. 6, 1138-1140, 1142, 1144, 1146, 1148 (1955) June.

Joining of aluminum-sheathed Nichrome coil directly to bottom of aluminum cooking utensil, which increases heat transfer efficiency by 400 percent, is achieved by a new brazing process developed by Selas Corp. A solid metal path for heat flow is developed. Process produces joints having strength and corrosion resistance comparable to welded joints of same alloys. Single and multiple automatic brazing stations are described.—INCO. 10549

3.7.3, 7.10

Bolt Materials for Underground Use. *Gas Age*, **115**, 38-39 (1955) June 2.

Addition of small amount of copper, nickel, or chromium appears to offer promise. Some bolt materials can be protected against corrosion by making them cathodic to the structures which they fasten. Photographs, table. 3 references.—BTR. 10580

3.7.3, 3.2.2, 6.2.5

On One Form of Intergranular Corrosion in Welds in Stabilized 18-8 Steel (Knife-Line Attack). YU. I. KAZENNOV. *Avtomaticheskaya Svarka*, **9**, No. 2, 91-93 (1955).

Study of conditions for incidence and ways of suppressing integranular knife-line attack in titanium- and niobium-stabilized 18-8 steels. Photographs, diagrams, table. 2 references.—BTR. 10418

Translation available: Henry Brutcher, P. O. Box 157, Altadena, California.

3.7.3, 3.5.8, 6.2.3

Corrosion Fatigue of Low-Carbon Steel Welded Joints. A. M. ABD-EL-WAHED. *Brit. Welding J.*, **2**, No. 6, 247-253 (1955) June.

Investigations into corrosion fatigue of welded joints are described. Material selected was 0.15 percent carbon steel and sodium chloride solution the corrosive medium. All-weld-metal specimens and specimens from heat-affected zone were included in tests. Endurance under corrosion fatigue of successive zones across welded joints is proportional to hardness values. Endurance of heat-affected zone is greater than that of base metal but effect of stress variation is more marked in former. Tables, graphs, photomicrographs.—INCO. 10459

3.7.3, 3.5.8, 7.10

Fatigue Analysis of Aircraft Bolts. H. G. BRILMYER. Huck Mfg. Co. *Aeronaut. Eng. Rev.*, **13**, No. 7, 48-54 (1955) July.

Describes tension fatigue tests on alloy-steel and aluminum Huckbolt installations, as well as standard aircraft (AN) bolt-nut combinations, which were conducted at Battelle. General description of Huckbolt and its installation by use of pneumatic production driving tools is included. Method is presented for use in determining tensile preload present in an installed fastener. Alloy-steel Huckbolt performed considerably better than AN bolts tested. Table, graphs, 19 references.—INCO. 10499

3.7.3, 5.3.4

The Roughness of (Steel) Surfaces After Various Pretreatments and Its Significance for Hot Galvanizing. (In German.) H. BABLIK, F. GOTZL AND E. NELL. *Metalloberflache*, **9**, No. 5, 69A-71A (1955) May.

An investigation of steel sheet: cold-rolled, as such or wire-brushed, chemically or electrolytically pickled; hot-rolled. Varying degrees of roughness are found. No galvanizing tests were made, but it is pointed out that the surface roughness affects the interfacial tension between steel and molten zinc and hence the galvanizing behavior, in respect of the uniformity of the coating in dry galvanizing and of the development of the alloy layer in wet galvanizing.—BNF. 10489

3.7.3, 6.2.5, 7.2

The Welding of Austenitic Chromium-Nickel Steel Piping and Tubing. Brochure, 1955, 32 pp. American Welding Society, 33 West 39th Street, New York 18, New York.

A committee report intended as a guide to prevent difficulties in welding austenitic stainless steel. While written specifically for piping and tubing, many of the recommendations are equally applicable to other forms of stainless steels.

A section devoted to the corrosion

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resistance of welds includes information on intergranular corrosion, stress corrosion cracking, crater corrosion, galvanic corrosion. Consideration is given also to sigma phase formation, suitability of various grades for welding and recommended rods for various grades. 10462

3.8 Miscellaneous Principles

3.8.2

Scientific Basis of Corrosion. U. R. EVANS. Paper before Symposium on the Corrosion of Instruments, Soc. of Instrument Technology, London, February 22, 1955. *Trans. Soc. Instrument Technology*, **7**, 123-124; disc., 133-135 (1955) September.

Brief consideration of chemical changes at surfaces of metals undergoing corrosive attack, in relation to electron mechanisms. Role of sulfur compounds and moisture is disclosed.—INCO. 10786

3.8.2, 3.6.8

Mathematical Studies of Galvanic Corrosion. Part II. Coplanar Electrodes with One Electrode Infinitely Large and with Equal Polarization Parameters. JAMES T. WABER AND MARSHALL ROSENBLUTH. *J. Electrochem. Soc.*, **102**, No. 6, 344-353 (1955) June.

The expressions for the potential and current density distribution have been derived for the two mathematically similar corrosion problems, a) tiny anodes buried in infinite cathodes and b) tiny foreign cathodic inclusions in a metal. The implication of using equal polarization parameters has been discussed. When the critical dimension of the tiny electrode becomes smaller than the polarization parameter, corrosion attack and the interfacial potential becomes more uniform over the galvanic cell. Figures and perspective drawings made to scale are included to illustrate the effect of the polarization on the distribution of potential in the corrodent and the diminishing variation of corrosion attack. (auth).—NSA. 10652

3.8.2, 3.6.8

Mathematical Studies of Galvanic Corrosion. Part III. Semi-Infinite Coplanar Electrodes with Equal Constant Polarization Parameters. J. T. WABER. Paper before Electrochem. Soc., Cincinnati, May 1-5, 1955. *J. Electrochem. Soc.*, **102**, No. 7, 420-429 (1955) July.

Mathematical analysis of a coplanar alternating array of long narrow electrodes was conducted subject to the limitation that polarization parameters for the anodes and cathodes are constant and equal. Interfacial potential and corrosion current parameters were computed for 18 values of a/α and for a/c equal to ½ and ¼. Four perspective drawings of the distribution of potential throughout the corrodent were made to scale to illustrate the influence of polarization. 13 references.—INCO. 10639

3.8.2, 3.6.8, 6.3.11

Mechanisms of Hydrogen Producing Reactions on Palladium. J. P. HOARE AND S. SCHULDINER. *J. Electrochem. Soc.*, **102**, No. 8, 485-489 (1955) August.

Hydrogen overvoltage on palladium in sulfuric acid and sulfuric acid plus sodium sulfate solutions was determined. Data showed that the overvoltage curves could be divided into three consecutive regions: A) η was linearly dependent on i; B) there was a Tafel relationship between η and i in which the b slope, depending on the pH of the solution, was equal to 0.030-0.042; C) depending on the pH of the solution, there was either a Tafel relationship between η and i with a b slope of 0.12, or η was virtually independent of i. Hydrogen overvoltage mechanisms were postulated for each of these regions. 12 references.—INCO. 10383

3.8.2, 6.2.2

Electrochemical Investigations of Corrosion of Single Crystals of Alpha Iron in Dilute Acids. (In German.) HANS-JURGEN ENGELL. *Arch. Eisenhuttenw.*, **26**, No. 7, 393-404 (1955) July 19.

Fundamental aspects of corrosion and electrochemistry for iron in acid solutions. Current density potential diagrams for α-iron in sulfuric, perchloric and nitric acids, characteristic etch figures, activity of local elements between differently oriented crystals in a crystal aggregate and results used to assess corrosion behavior of metallic materials on the base of electrochemical measurements are discussed.—INCO. 10501

3.8.2, 6.2.5

Corrosion of Stainless Steel in Ferric Chloride Solution. H. A. LIEBHAFSKY AND A. E. NEWKIRK. *Corrosion*, **12**, No. 2, 92t-98t (1956) Feb.

Rapid corrosion occurs through pitting when annealed Type 302 stainless steel sheets are suspended in ferric chloride solution. Dissolution of sample can approach completion with unexpectedly little alteration in appearance of surface.

Rate of weight loss with different samples is surprisingly similar with the following four zones distinguishable in most cases: 1) a short induction period, 2) a zone of fairly constant, slow rate, which changes slowly into, 3) a zone of rapid rate and finally (when less than 2 percent of the sample remains) into 4), a zone in which the rate is negligible.

Distinct rate zones do not exist if one side of the stainless steel plate is covered with a thin film of evaporated gold. Corrosion then is rapid at the outset and the rate gradually decreases.

Induction period experiments- done with the aid of a microbalance show that corrosion begins within one minute after a clean dry coupon is immersed in ferric chloride solution. It has been demonstrated that measurements of corrosion rate in this system are simple and relatively reproducible. Extension of these measurements should yield valuable fundamental information about this corrosion process. 10695

3.8.2

Corrosion and Residual Current. HERIBERT GRUBITSCH. *Werkstoffe u. Korrosion*, **5**, No. 12, 500-508 (1954) December.

Experiments carried out with platinum oxygen electrolyte anode cells were designed to show that current—and therefore corrosion rate—follow Fick's first diffusion law. The following results are given: 1.) With flowing current in an oxygen-depolarized cell, the current density is dependent upon the pH and upon the potential difference of the working cell. The diffusion formula does not explain this dependence. 2.) With current break and make a quantity of current flows which is composed of at least three components: the charge of the double layer, the rebuilding of the diffusion zone, and the depolarization of the platinum cathode. As soon as the original steady current is restored there follows only depolarization of diffusing oxygen, resulting in a stationary state. The amount of current which flows up to the time of re-establishment of the stationary state is proportional to the square root of the open-circuit time. This shows that both the re-establishment of the diffusion zone and the adsorption of oxygen on the platinum are rate-determining diffusion processes. The number of C are proportional to the hydrogen ion concentration and the potential difference of the cell. The intermediate formation of a loose absorption compound $Pt\text{-}HO_2^*$ is indicated. 3.) Potential/time curves do not point to the formation of an independent platinum oxide. 4.) The capacity of the double layer rises proportionately with the potential difference of the working cell. 30 references.—MA. 9753

3.8.2, 6.3.3, 1.6

Electrode Processes. Technical Report No. 1. Interaction of Chromium (VI) Anions with Chromium Metal Surfaces. L. O. MORGAN AND S. KOTTLE. Texas Univ., Austin, May, 1955, 61 pp.

The adsorption of Cr^{6+} on chromium metal surfaces and the resultant electrode potential changes have been correlated with the pre-treatment of the chromium metal and with variations in the surfaces arising in differences in measured roughness. The electrode potential changes were ascribed in part to incorporation of polarized anions in the electronic double layer associated with the metal surfaces.—NSA. 10605

3.8.3, 6.2.2

The Passivity of Iron in Neutral and Slightly Acid Solutions. (In German.) K. G. WEIL AND K. F. BONOEFFER. *Z. phys. Chem.*, **4**, No. ¾, 175-191 (1955) June.

Passivation of iron and its behavior in solution varying from 2 to 6 pH. Graphs, tables, diagram. 11 references.—BTR. 10332

3.8.3, 6.2.2, 3.6.5

The Difference in Potential Within the Passive Layer of Iron. (In German.) KLAUS J. VETTER. *Z. phys. Chem.*, **4**, No. ¾, 165-174 (1955) June.

Theoretical and experimental determination of the potential difference at the oxide-electrolyte phase boundary; discusses Flade potential and corrosion; possible effect of a high-energy oxide or of increased corrosion on the Flade potential. Diagram. 11 references.—BTR. 10398

3.8.4

The Anodic Dissolution of Amalgams at Stationary Electrodes. A. HICKLING AND J. MAXWELL. *Trans. Faraday Soc.*, **51**, No. 1, 44-54 (1955).

Measuremnets of the speed of anodic solutions are reported for amalgams of cadmium, zinc, thallium and lead, with 0.0005-1 at.-% metal and amalgams of copper and manganese with 0.0005-0.01 at.-% metal. The rate-determining process is the diffusion of the dissolved metal in mercury up to the amalgam/electrolyte interface. The results permit of simple quantitative treatment in terms of the Nernst diffusion layer if allowance is made for the variation in thickness of the layer with concentration which is to be expected under conditions of natural convection. Equations are formulated for calculating the limiting current of dissolution of any amalgam and the time taken for any fraction of an amalgam to be used up when it is dissolving at the limiting rate. 14 references.—MA. 10779

3.8.4

A Kinetic Study of the Oxidation of Sphalerite. Part II. Technical Report No. XVIII. JOHN N. ONG, JR., MILTON E. WADSWORTH AND W. MARTIN FASSELL, JR. Institute for the Study of Rate Processes, Univ. of Utah. U. S. Atomic Energy Comm. Pubn., AECU-3007, Feb. 7, 1955, 20 pp.

The temperature and oxygen concentration dependence on the reaction of sphalerite in oxygen at pressures from 6 to 640 mm Hg have been investigated in the temperature range 700 to 870C. Sphalerite has been found to oxidize linearly over this entire temperature and pressure range. At higher rates considerable self-heating was observed. The dependence of the oxidation rate on the oxygen concentration may be expressed by: Rate $= k'\Theta$, where k' is the specific rate constant and $\Theta = K_1\text{-}(O_2)/(1+K_1[O_2])$, where K_1 is the equilibrium constant for the adsorption of oxygen on sphalerite. Values of the activation energy and the enthalpy of adsorption were found to be 60.3 and —59.6 kcal/mole, respectively. Data have been presented indicating conditions under which either a sulfatizing or an oxidizing rate may be obtained. (auth).—NSA. 10597

4. CORROSIVE ENVIRONMENTS

4.6 Water and Steam

4.6.12, 4.6.10

How to Prepare a Sour Brine for Subsurface Injection. T. M. DOSCHER AND R. N. TUTTLE. Paper before 18th Tech. Conf. on Petroleum Production, Pennsylvania State University, October 6-8, 1954. WORLD OIL, **140**, No. 4, 160, 162, 167 (1955) March.

Present day methods of removing hydrogen sulfide from flood water by aeration are not satisfactory because of corrosive nature of aerated water. Corrosion occuring downstream of filter loads injection water with corrosion products. New method for removing hydrogen sulfide involves stripping mixture of carbon monoxide and nitrogen. Finished brine contains no traces of hydrogen sulfide or oxygen and is insufficiently corrosive to warrant use of corrosion inhibitors. Sequestering agents should be added to keep in solution whatever corrosion products may form. Flow sheet of proposed water treating system is given.—INCO. 10054

4.6.13, 8.1.4

Plating Wastes: A Review of Research. D. G. FAULKE AND R. F. LEDFORD. *Metal Finishing*, **53**, No. 1, 67-75 (1955) Jan.

Review of research work being carried out by various U. S. organizations and universities. Disposal of cyanides; effect of plating wastes on sewage treating plants; analysis of plating wastes; disposal of acid pickle liquors; plant design. 63 references.—BNF. 9986

4.7 Molten Metals and Fused Compounds

4.7, 8.4.5

Role of Liquid Metals in Nuclear Power Development. J. W. TAYLOR. Atomic Energy Res. Establishment. *Research*, **8**, 102-105 (1955) March.

Liquid metals have potential application in reactor technology as coolants and heat exchange media, carrier media for nuclear fuel and extraction agents in processing spent fuel. The advantages and disadvantages of liquid metals as coolants are discussed and the other applications for liquid metals are reviewed briefly. Solutions to fundamental questions on corrosion mechanisms and structure and properties of liquid metals are necessary before the full potentialities of liquid metals in nuclear power can be realized.—NSA. 9867

4.7

Effect of Oxygen on Mass Transport of Stainless Steel Components in Sodium. J. W. MAUSTELLER AND E. F. BATUTIS. Mine Safety Appliances Co., Contract NObs-65426, Technical Report 36, March 16, 1955, 18 pp.

The transport of some radioactive Type 347 stainless steel constituents in 925 degrees F sodium has been studied in isothermal systems operated at oxygen contents of 0.010, 0.005 and 0.003 wt. % oxygen. Ratios of the transfer rate of the parent stainless steel at high and low oxygen contents were 54/1, 17/1, 5/1 and 4/1, based on transport of Co^{60}, Fe^{59}, Ta^{182} and Mn^{54} respectively. Transport rates of the stainless steel at high oxygen level based on transport of the source isotopes were 12, 541, 58 and 272 μg ss/cm^2 active stainless steel/mo. Concentrations of tantalum, antimony and cobalt in 925 degrees F sodium were 7.7×10^{-3}, 0.33 and 3.0×10^{-4}ppm at 0.010 wt. % oxygen. In sodium containing 0.003 wt. % oxygen the concentrations dropped by a factor of five. (auth).—NSA. 10317

4.7

The Mass Transfer Properties of Various Metals and Alloys in Liquid Lead. J. V. CATHCART AND W. D. MANLY. *Corrosion*, **12**, No. 2, 87t-91t (1956) Feb.

The relative resistance to mass trans-

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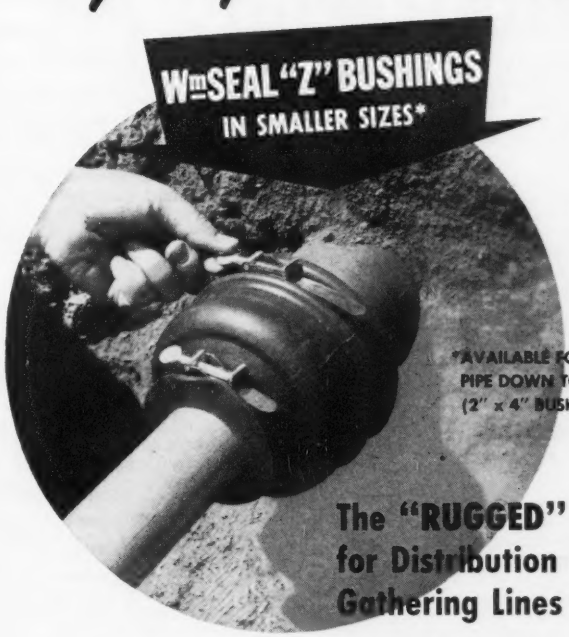

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fer in liquid lead of 24 metals and alloys were measured. Tests were performed in small quartz thermal convection loops. The test temperature was about 800C with a thermal gradient of 300C existing across the loops. Of the metals and alloys studied, only columbium and molybdenum exhibited a high resistence to mass transfer. Nickel and nickel-rich alloys were highly susceptible to mass transfer. Evidence is presented to show that alloys in which a tendency toward intermetallic compound formation exists show a higher resistance to mass transfer in liquid lead than do their pure metal components. 10701

4.7, 1.6

Attack on Metals by Bismuth-Lead-Tin Alloy at Elevated Temperatures. WALTER D. WILKINSON. Argonne National Laboratory. U. S. Atomic Energy Commission Pubn., ANL-5262, January, 1955, 73 pp.

The alloy 52 bismuth-32 lead-16 percent tin by weight does not attack molybdenum at 800C or beryllium at 500C. Aluminum, titanium and zirconium were damaged. Iron is insoluble but was subject to intergranular attack. Tables, graph, diagrams, photographs, micrographs. 7 references.—BTR. 10345

4.7, 1.6

Liquid Metal Technology. Final Report (A Review of the Work from May, 1949 to May, 1954, With Abstracts of Reports Issued). R. C. WERNER. Mine Safety Appliances Co., March 29, 1955, 77 pp.

A final summary is presented of the various activities which have been carried out on liquid sodium and sodium-potassium plumbing systems. Results on heat transfer, flow properties, corrosion tests, accessibility, sodium cleaning and tests on valves, bellows, pumps, etc. are included. Approximately half of the report consists of abstracts of the various technical reports and memos which have been issued under the contract.—NSA. 10331

5. PREVENTIVE MEASURES

5.1 General

5.1

Process for the Prevention of Corrosion: General Report. (In German.) WILLI MACHU. *Chem.-Ing.-Tech.*, **27,** No. 7, 403-409 (1955) July.

The economic importance of corrosion problems and the considerable variety of corrosion phenomena; methods used in technology for protection against corrosion; and a summary of the content of lectures held at the Corrosion Convention, 1954 in Frankfurt/Main. 16 references.—BTR. 10570

5.2 Cathodic Protection

5.2.1

Controlling Corrosion with Cathodic Protection. H. R. LUDEKER. *Metal Progress*, **68,** 86-90 (1955) August 1.

Corrosion, which costs our country billions of dollars each year, can be controlled by interposing an electrical resistance in the corrosion circuit or by limiting the difference in potentials of the anodic and cathodic areas. Photographs, diagram.—BTR. 10450

5.2.1

Cathodic Protection of Underground Structures. W. GODFREY WAITE. *Corrosion Technology*, **2,** Nos. 2, 3, 47-49, 83-86 (1955).

An account of the principles of cathodic protection is given, with a discussion of the use of magnesium anodes and inert anodes with applied current. The applications and limitations of the method are surveyed.—MA. 10336

5.2.1

Underground Pipeline Corrosion and Cathodic Protection. J. F. DAY. Paper, Wales and Monmouthshire Junior Gas Assoc. Mtg. *Gas J.*, **281,** 168-170, 176 (1955) January 19.

The electrochemical theory of corrosion is reviewed and the principles of corrosion prevention by cathodic protection are described. The use of soil resistivity surveys in designing a protective system for pipelines is outlined. 10740

5.2.1, 4.5.1

Cathodic Protection of Underground Structures. A Report of Corrosion Commission II for the Study of Underground Corrosion of Pipe. (In Dutch.) J. F. BOGTSTRA AND M. OUDEMAN. Publication 35 of the Metaalinstituut T.N.O. Afdeling Corrosie, Delft, Holland, July, 1955, 41 pp.

This appears to be designed in the manner of a handbook of procedures in cathodic protection of underground structures. Electrochemical testing, covering potentials, galvanics, concentration cells, aeration, stray currents, polarity is included. Investigation of the source of corrosion covers soil aggressiveness, resistance, pipe potential measurements. installation data include external current sources, galvanic anodes, isolation, locating ground beds and testing. 10871

5.2.1, 5.2.4, 4.5.3

A Study of Protective Criteria on a Pipe Section in a Uniform Environment. L. P. SUDRABIN. *Corrosion*, **12,** No. 2, 60t-66t (1956) February.

The effect of the reference electrode location upon the meaning of the pipe-to-reference electrode potential is demonstrated by use of a model pipe section. Known anodic areas of representative shape and position are established on iron pipe by coupling high purity zinc plates through measuring circuits.

It is found that the protective potential gradient, including the (IR drop) potential effects the system is entitled to, moves farther from the pipeline as the lines of corrosion current flow increase in length. Another finding is that the potential gradients of the smaller local corrosion cells are not discernible by surface potential measurements.

The following generalizations for establishing the effectiveness of protective current on bare pipe have support:

1. Long line corrosion currents are controlled when the protective potential (—.85 volts) is measured to a Cu-$CuSO_4$ reference electrode in a remote location (100 feet away or farther from pipeline). Intermediate and local cell corrosion currents are reduced.

2. Long line and intermediate corrosion currents are controlled when the protective potential is measured to a reference electrode placed over the pipeline. Local cell corrosion currents are reduced.

3. Long line, intermediate and local cell corrosion currents are controlled when the protective potential is measured close to the pipe surface.

Measurements 1 and 2 are critical to stray current, shielding and anode potential gradient effects. 10763

5.2.1, 5.4.5

Economic Cathodic Protection. B. G. BRAND. *Battelle Tech. Rev.*, **4,** 49-52 (1955) May.

Use of protective coatings in cathodic protection of installations, e.g., off-shore drilling equipment, pipelines, ships and condenser water boxes, by either sacrificial anodes or applied potential methods, is reviewed. 10678

5.2.1, 7.5.5

Cathodic Protection of Tank Bottoms. J. J. MEANY, JR. *Oil Gas J.*, **54,** No. 25, 95-96, 98, 100 (1955) Oct. 24.

Stray currents and a cinder fill complicated protection of two storage tanks, but by planning the protection system before tanks were built, it was possible to bury anodes and reference electrodes beneath the tanks. Tests show the null-circuit method was the only one capable of measuring true amount of cathodic protection current required. Diagrams.—INCO. 10893

5.2.1, 8.9.3

When Does Cathodic Protection Pay Out? DEAN C. GLASS. *Pipe Line Industry*, **2,** 37-38 (1955) June.

Survey of pipe line companies shows some surprising results as to the cost and pay-out of cathodic protection. Tables. —BTR. 10578

5.2.1, 8.9.3

Cathodic Protection on the Biggest Inch Line. Part II. N. K. SENATOROFF AND W. M. SCHILLING. *Pipe Line News*, **27,** 50+9 pages (1955) August.

Details of a $100,000 complete cathodic protection system for this 30-in. wrapped gas line. Tables, graphs, diagram. 6 references.—BTR. 10414

5.2.2

Practical Application of Zinc Anodes for the Cathodic Protection of Pipelines. (In German.) B. TRAUTMANN. *Metall*, 9, No. 15/16, 649-651 (1955) August.

Current required for zinc anodes under different soil conditions; properties of zinc anodes; types of back-fill for different soils and factors affecting the economy of this method. Tables, graphs, diagram. 2 references.—BTR. 10343

5.2.2

Control of the Corrosion of Dock Gate by Zinc Anodes. M. NAKAGAWA AND T. KAKEI. *Corrosion Engineering*, (Japan) **4,** No. 2, 84-85 (1955) April.

A painted dock gate (approx. 2000 ft^2) was protected by thirteen zinc anodes of super high grade. A graph and table show the current out-put and consumption rate of each anode and a table showing the results obtained with steel test pieces is included. It was found that the super high grade zinc anode shows steady current out-put and excellent current efficiency in sea-water.—JSPS. 10830

5.2.2

Cathodic Protection 1955. F. D. MURPHY. *Light Metals*, **18,** No. 206, 146 (1955).

A general review of the theory and practice of the use of magnesium and recently special magnesium alloys, as anodes in the galvanic or sacrificial protection of ships' hulls, buried pipelines and underwater structural steel work. The advantage of this system over the "impressed current" system is that no external source of current is required, leading to greater simplicity and reliability. 8 references.—MA. 10832

5.2.2, 1.4

Applications of Light Metals: Ca-

thodic Protection. *Light Metals,* **18,** No. 206, 145 (1955).

A bibliography, corrected to September, 1954, of articles which have appeared in *Light Metals* dealing with the use of magnesium anodes for the "sacrificial" protection of steel work, mainly buried steel pipes.—MA. 10852

5.2.2, 5.3.2, 5.4.5

How Zinc Controls Corrosion. Brochure, 1955, 32 pp. Am. Zinc Inst., New York.

An illustrated booklet describing how zinc in various forms provides protection against corrosion. Metallic zinc coatings applied by hot dip galvanizing, electro-galvanizing, Sherardizing or spraying, the use of zinc pigments in corrosion resistant paints and the use of zinc anodes for cathodic protection are considered. The advantages and applications of each method of protection are discussed. A list of references to relevant articles, ASTM Standards and U. S. Government Specifications is appended.—ZDA. 10704

5.2.2, 5.4.5

Insulating Coatings and Their Influence on the Cathodic Protection of Ferrous Metals by Means of Magnesium Anodes. (In French.) B. RACLOT. *Metaux, Corrosion-Industries,* **30,** No. 358, 258-261 (1955) June.

Importance of the combination of coating properties and cathodic protection, depending upon the nature of the insulating material and conditions of application. Tables, graphs.—BTR. 10618

5.4 Non-Metallic Coatings and Paints

5.4.2, 6.4.2

Porcelain Enamels for Aluminum. J. I. MUELLER. *Trend* (in Engineering at the University of Washington), **7,** No. 2, 21-24 (1955) April.

In attempting to develop lead-free enamels, the most promising compositions appear to be those based on either phosphate or alkaline fluoroborate glasses. Preheating the metal to increase the oxide layer was found the most satisfactory preparation.—BNF. 10896

5.4.5

Electrochemical Study on Protective Action of Paint Films. Part I. Impedance Measurement of Painted Steel. G. OKAMOTO AND T. MOROZUMI. *J. Electrochem. Soc. Japan,* **23,** No. 1, 15-18 (1955) Jan.

Electromechanical study on the protective action of organic coatings on metal has been made by measuring the impedence of the coating on steel specimens in 3% sodium chloride solution over a frequency range of 0.2-20 Kc/s. Distinct variations are observed in the resistance-frequency and capacity-frequency curves during the immersion.

Applying an equivalent circuit model to the coating, it is reasonably interpreted that these variations are due to the detachment of the surface film and its porosity increase. It is also possible to calculate the detached area of the film.—JSPS. 10921

5.4.5

Protective Coatings for Corrosion Control. N. T. SHIDELER. *Virginia Polytechnic Institute, Bulletin,* Engineering Experiment Station Series No. 102, **48,** No. 10, 20-32 (1955) August.

Review of surface preparation, application and properties of drying oil base, oleoresinous, synthetic and bituminous coatings. 6 references.—BTR. 11012

5.4.5

Primers. W. WEINER. *Ind.-Lack.-Betrieb,* **23,** No. 6, 139 (1955).

A discussion of wash primers. German practice now includes use of a wash primer with some hiding power as well as the transparent type.—RPI. 11042

5.4.5

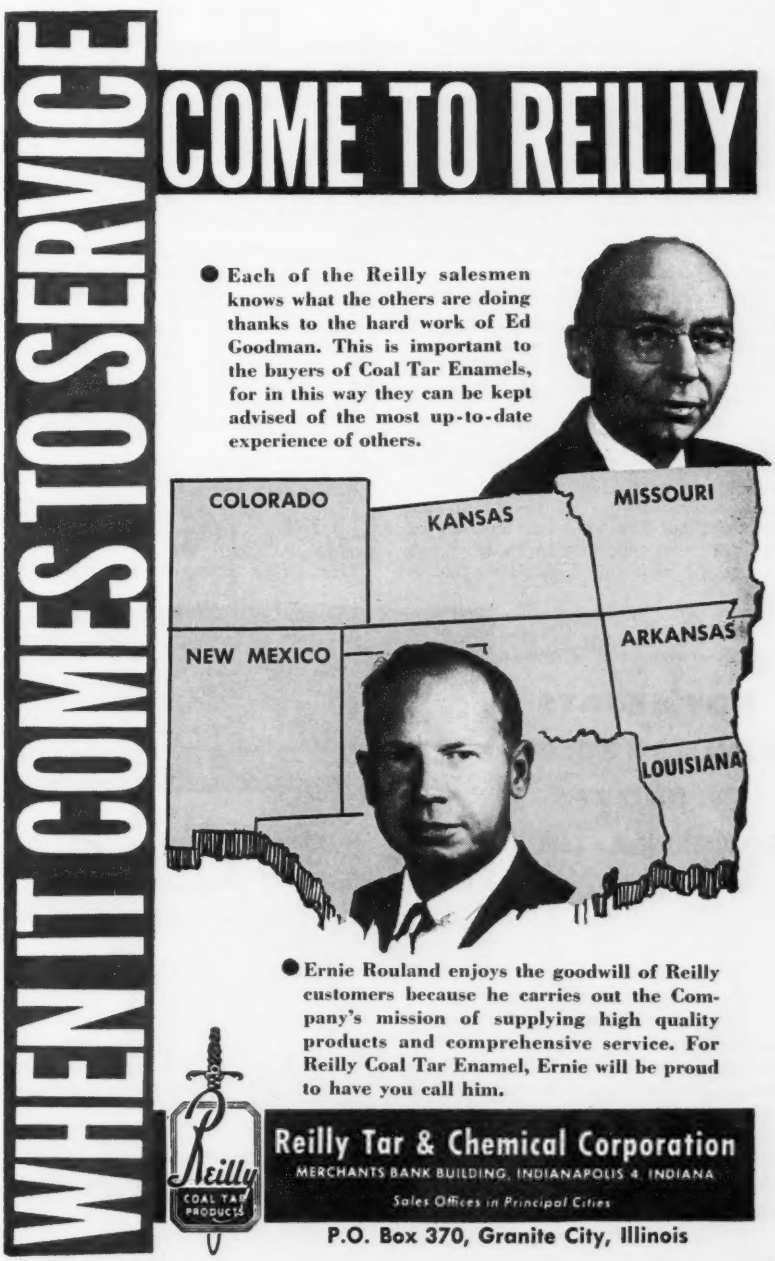
Maintenance Painting in the Steel Industry. C. SCHOFIELD. Republic Steel Corp. *Iron Steel Engr.,* **32,** No. 9, 65-73; disc., 73-74 (1955) Sept.

Discusses proper surface preparation, use of wetting oils and importance of rust removal, mechanics of application, temperature and weather conditions in painting iron and steel structures and stresses the need for standardization of procedures and materials. Of the two methods of specifying paints, formula and performance specification, performance is the more desirable. Function of control and performance evaluation laboratories are considered. Minimum equipment requirements for evaluation laboratory include weatherometer, water immersion tank, salt spray tank, humidity cabinet and outdoor exposure rack. Illustrations.—INCO. 10977

5.4.5, 1.3

Organic Films in the Protection (Against Corrosion) of Structures. (In German.) W. SANDOW. *Schweiz. Archiv angew. Wiss. u. Tech.,* **21,** No. 3, 95-99 (1955).

A review dealing with the protection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of buildings. Masonry, concrete, and wood, as well as metals, can be protected by organic coatings. Light-alloy structures need special protective measures only if they are exposed to exceptionally corrosive atmospheres. Wash primers of the type developed for steels, often containing zinc chromate and phosphoric acid, are very successful for aluminum alloys also, primarily because they ensure excellent adhesion of all coats to the surface. For copper-base alloys, too, the wash primers are widely used, sometimes with a second cellulose coat and generally with a top coat of alkyd resin enamel. Zinc surfaces are often covered with an oxide film which prevents adhesion of painted coats. Cellulose primers are best on this material.—MA. 10973

5.4.5, 6.4.2

Aluminum Primers: The Importance of a Low Lead Content. GIUSEPPE LUFT AND PAOLO DEBOVE. *Ind. vernice*, **9**, 33-37, 61-64 (1955); *Chem. Absts.*, **49**, No. 17, 12015 (1955) September 10.

Alkyd-based zinc chromate primers, to which 0.2, 0.5, 1, 2, 3, 5, and 33% lead in the form of Pb_3O_4 and a combination of 0.2% lead with 1% copper (as cuprous oxide) had been added, were sprayed on several types of aluminum panels and allowed to dry for 10 days at 20C. The film thickness everaged 190 g./sq. m. but was somewhat greater with the 33% lead and with the lead-copper paints. The panels were first subjected to a mandrel test but showed no significant effect of the lead content. Corrosion tests were run in a 3% salt spray (10-hour exposures, 14-hour rest period) and by direct exposure to a marine atmosphere at Arenzano near Genoa. In the salt spray test for 120 days, films containing 0.2-0.5% lead were not corroded; those with 1-5% lead showed corrosion within 60 days, and those with 33% lead or with the lead-copper combination were corroded after 30 days. However, one type of aluminum (AP 5 H70) was uncorroded after 120 days with even 5% lead, but 33% lead and lead-copper corroded this type just as badly. When the panels were put through a cycle of 10 hours at 0C and 14 hours at 80C, corrosion became more pronounced even at low lead content. Exposure for 90 days to salt spray and subjection to conical mandrel tests showed light corrosion with less than 1% lead, but much more severe corrosion at greater lead concentrations. Corrosion of the alloy P-AC 4 GM was much more pronounced than on AP-5. It is concluded that lead should not exceed 0.2%, and copper should be entirely absent in varnishes directly in contact with aluminum.—ALL. 10929

5.5 Oil and Grease Coatings

5.5.1, 5.8.2

Mineral Oils and Greases for Temporary Corrosion Protection. W. PRESTING AND G. KEIL. Paper, Fachberband Energie, Kammer der Technik Lubricant Symp., Berlin, December 8, 1954. *Technik*, **10**, 232-236 (1955) April.

The mechanism of surface protection of metals is reviewed and the passivating effect of corrosion inhibitors such as sulfonates, nitrites and nitrogen-acylated amiono acids, etc. incorporated into various grades of vaseline for temporary protection of machinery parts is discussed, with performance diagrams. Resin coatings and impregnated paper wraps are noted. 19 references. 10958

5.5.3

Corrosion Preventing Agent With a Limited Protective Action. (In German.) WILFRED POHL. *Erdol u. Kohle*, **8**, No. 8, 552-556 (1955) August.

Describes different corrosion preventing agents, mainly of a greasy constitution for application in storing, transportation and during production. Also gives suggestions for selection of various types of compounds. Table.—BTR. 10954

5.5.3

Dewatering Fluids. Brochure, May, 1955, 38 pp. Available from C. C. Wakefield & Co., Ltd., Grosvenor Street, London, W. 1.

Dewatering fluids act by mechanical displacement of the film of moisture by a film of the fluid itself; they are essentially corrosion preventives containing surface-active agents. While mainly intended for ferrous metals, they find application with aluminum, magnesium, copper alloys, chromium and cadmium; a wide range of fluids is available. Properties and uses of the various fluids, efficiency, industrial applications (removal of metal working coolants, phosphating, anodizing, electroplating, pickling, shot blasting, machining, preventing finger-print corrosion, etc.).—BNF. 11039

5.6 Packaging

5.6.2, 5.4.5

Corrosion Prevention by Spray Packaging. D. W. HARBOUR. *Corrosion Prevention and Control*, **1**, No. 5, 288-291, 295 (1954) July.

Two techniques of spray packaging are outlined. In the first the object is surrounded by a "sealed envelope" of vinyl plastic, with a dessicant inside the envelope; there may be an additional coating of bitumen. For the "strippable film" coating a layer of e.g., ethyl cellulose or a vinyl base compound is applied by dipping, brushing or spraying. In *ibid*, **1**, No. 7, 418-420, 427 (1954) Sept., J. FEASEY ("Spray Packaging in Practice") describes techniques and applications in more detail.—BNF. 9749

5.7 Treatment of Medium

5.7.1, 4.6.2, 4.6.4

A Survey of Water Conditioning Practices. J. W. GIBSON. *Petroleum Engr.*, **27**, No. 10, C44-C46, C48-C49, C53 (1955) September.

Reviews recent progress in processes available for conditioning water in cooling towers, boiler feedwater systems and cooling systems to allow maximum re-use within economical limits. External processes discussed include sodium- and hydrogen-cation exchange, hot- and cold-lime precipitation, salt splitting and demineralization. Internal methods considered include control of pH by sulfuric acid, sulfur burners and sulfur dioxide, control of microorganisms, use of Glucosates and vapor-phase cooling. —INCO. 10789

5.7.3, 5.7.5

Vacuum Degasification Shows Its Versatility. R. H. MARKS. Permutit Co. *Power Eng.*, **59**, No. 8, 92-95 (1955) Aug.

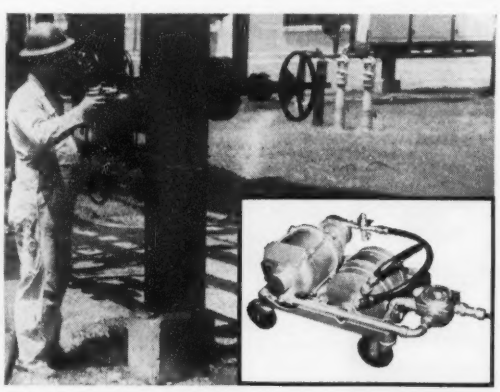
Basic theory and operation of vacuum degasification and its application to five installations: chemical plant cooling water, water for oil flooding operations, boiler feedwater makeup for by-product plant and for a power plant and Cosmotron cooling water. Corrosion at chemical plant required replacement of heat exchanger tubes every 18-24 months; vacuum degasification system reduced replacement and water consumption. Flow diagram of demineralization system of Cosmotron cooling water at Brookhaven is given; inlet system has a stainless steel water box. —INCO. 10567

5.8 Inhibitors and Passivators

5.8.1

Inhibition of Metallic Corrosion in

HOT SPRAYS 2 MILLION SQ. FT. . . . PROVES LONGER LASTING FILM



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Aqueous Media: A Review. HARRY C. GATOS. *Corrosion*, **12**, No. 1, 23t-32t (1956) January.

A brief discussion of corrosion processes from the electrochemical standpoint is given along with some of the electrochemical factors affecting corrosion. Organic and inorganic inhibitors are discussed separately and the mechanisms proposed for explaining their action as polarizers of the local corrosion cells are reviewed. Several experimental approaches to the study of corrosion inhibitors are given. In this connection a number of inhibitors are listed and their applications given. 10551

5.8.2

Application of Glassy Phosphates for Corrosion Control. GEORGE ILLIG. *Virginia Polytechnic Institute Bulletin.* Engineering Experiment Station Series No. 102, **48**, No. 10, 4-10 (1955) August.

Use and mechanism of action in industrial and municipal water systems. 11 references.—MR. 10810

5.8.2, 4.4.6

An Evaluation of Corrosion Inhibitors for Use in Aircraft Fuels. J. A. KRYNITSKY AND R. L. SHULER. Naval Research Lab., Rept. No. 4496, February 8, 1955, 30 pp.

Thirty-two products submitted by industry were screened for use in aviation fuels as anti-corrosion additives. Tests performed included determination of ferrous corrosion activity, water extractability, fuel solubility, as content tolerance using distilled, buffered and sea water and compatabilities with other inhibitors. Test temperature was 100F, corrosive medium was synthetic sea water and test specimens were of grade 1020 cold-finished carbon steel. Fuels used were JP-4, 115/145 avgas and ASTM reference grade isooctane. Tables, photographs of specimens.—INCO. 10419

5.8.2, 4.6.1

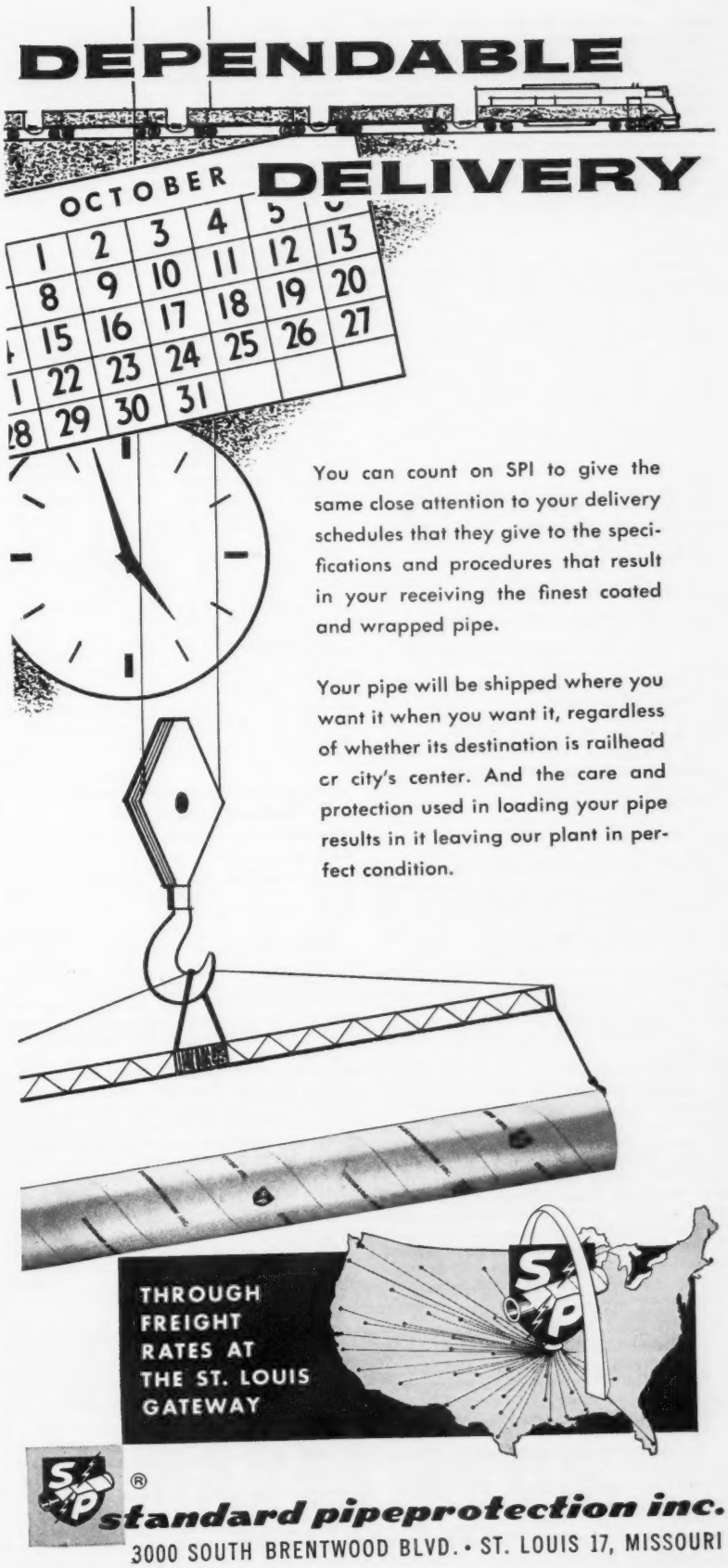
Of What Use Are Chemical Treatments in Controlling Corrosion? S. T. POWELL AND L. G. VON LOSSBERG. Paper before Am. Soc. Mech. Engrs., Ann. Mtg., New York, November 28-December 3, 1954. *Mech. Eng.*, **77**, No. 6, 495-498 (1955) June.

Trends in supplementary chemical treatments are reviewed. Sulfur compounds as reducing agents, use of sulfite-treated water for desuperheating, hydrazine treatment, pH control of condensate returns and use of amines in power plants are considered. Physical and chemical data on hydrazine solutions are given and operating experience is described. Diagram shows arrangement of equipment for safe handling and feeding of strong chemical solutions after dilution. Graphs.—INCO. 10625

5.8.2, 4.6.4

Controlling Corrosion in Cooling Systems. T. J. DEVEREUX. W. H. & L. D. Betz Company. *Western Metals*, **13**, No. 6, 53-54, 56 (1955) June.

Discusses the factors responsible for the higher susceptibility of recirculating cooling water systems to high corrosion rates, including saturation with dissolved oxygen, increase of total dissolved solids causing proportionate increase in conductivity, turbidity due to dust and growth of micro-organisms. Treatment with silicates, polyphosphates and chro-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mates s considered. Best overall method of eliminating corrosion is use of both polyphosphates and chromates, known as the Dianodic method. Average penetration under low phosphate treatment was 0.021-inch per year, 0.0033-inch per year under conventional chromate treatment, and 0.0020-inch per year with Dianodic treatment. Chart shows percent pit reduction for various mixtures of phosphate and chromate.—INCO. 10531

5.8.2, 8.4.3

Corrosion Inhibitors in Petroleum Refinery Service. *Corrosion Technology,* **2,** No. 11, 343-347 (1955) November.

Reviews the principles of passivation and evaluates the inhibitive properties of anodic inhibitors (sodium chromate and sodium nitrite), cathodic inhibitors (lime and sodium carbonate, glassy phosphates, calcium bicarbonate), and organic inhibitors (amines and salts of fatty acids).—INCO. 10728

5.8.3

Inhibition of Acid Dissolution of Metals. Part I. Some General Observations. A. C. MAKRIDES AND NORMAN HACKERMAN. *J. Phys. Chem.,* **59,** 707-710 (1955) Aug.

A mechanism for inhibition of metal dissolution is given and the important parameters are pointed out. Tables. 17 references.—BTR. 10566

5.8.3

Behavior of Various Inhibitors in Galvanic Corrosion. (In Italian.) G. BOMBARA AND F. GIANNI. *Riv. combustibili,* **9,** No. 4, 297-313 (1955) April.

Evaluation of inorganic inhibitors by means of galvanic polarization curves. Diagrams, tables, graphs. 7 references. —BTR. 10494

5.8.3

Effect of Thiourea Compounds on Dissolution Rate of Iron and Mild Steel: Adsorption and Inhibition, Steady State and Potential. A. C. MAKRIDES AND N. HACKERMAN. *Ind. & Eng. Chem.,* **47,** No. 9, 1773-1781 (1955) Sept.

Effect of thiourea and seven of its N-substituted derivatives, which can both accelerate and inhibit dissolution in acid, was studied with respect to dissolution rate of mild steel powder and Armco iron coupons. Acceleration is attributed to hydrogen sulfide produced by cathodic reduction of these compounds, while inhibition is result of retardation of the anodic process. Effects of ferrous ion, change in acid concentraiton, temperature coefficient, solvent, oxidizing agents and small surface areas are observed. Time effects in inhibition were studied using steel powder with relatively large surface area and s-diethylthiourea, time dependence being studied by following the rate of hydrogen evolution. Numerous graphs and tables, 29 references.—INCO. 10879

5.8.3

A Theoretical Basis for a New Method of Investigating Corrosion Inhibition. J. G. JEWELL. Paper before Electrochem. Soc., Boston, October 3-7, 1954. *J. Electrochem. Soc.,* **102,** No. 4, 198-205 (1955) April.

Derives an inequality that bounds the derivative of the corrosion current with respect to concentration of a strictly cathodic inhibitor. In special cases, inequality is a direct consequence of Cupr's generalization of Muller's electrochemical model of corrosion. Upper bound of derivative is calculated from measurements of potential difference between a corroding electrode and a reference half-cell at different concentrations of inhibitor and different densities of externally applied current. Theory provides a rapid method of screening cathodic inhibitors to eliminate from further consideration certain ones shown to be ineffective. Derivation of equation, diagrams.—INCO. 10307

5.8.4, 4.6.4

Metallic Phosphates in Cooling Water Treatments. W. J. STONE. *Corrosion Technology,* **2,** 13-17 (1955) January.

Mixtures of metal phosphates which are produced as by-products of the phosphate industry have superior corrosion-inhibiting properties in water systems and at the same time prevent scale deposition in those sections where the water has a tendency to form scales. Their use makes chemical control of acidity in water systems much less critical. Metallic phosphates have been successfully manufactured with strontium, calcium, barium, lead, cadmium magnesium, copper, antimony, manganese, molybdenum, vanadium, silicon, iron, and aluminum. Combinations of the above metals are also possible. The properties of these compounds vary widely. In addition to their uses in water systems some have shown promise as algaecides; others are good corrosion inhibitors in low pH systems or are effective in removing scale or in preventing corrosion in brines. One combination seems to retard the breakdown of sodium bicarbonate to the carbonate. The field of use of these metal phosphates is seemingly limitless. —PDA. 10351

5.9 Surface Treatment

5.9.2, 5.3.4, 5.8.2

Inhibited Acids in Plating Cycles. J. W. CARROLL. *Metal Finishing,* **53,** No. 3, 60-63 (1955) March.

Advantages gained by use of inhibited acids include less hydrogen evolution and less hydrogen absorbed by metal, improvements in appearance of metal, rinsing properties and stripping operation, reduction of operation errors and longer allowable pickling time or higher pickling tempeartures. Test was conducted on steel panels plated in a bright nickel bath to show effects of inhibitor film on adhesion of deposit. To show effect of inhibitor on plating bath, inhibitors were added directly to a bright nickel plating bath, while a third test evaluated effect of inhibitor film on appearance of bright nickel deposits. A typical electroplating cycle employing inhibited acids, the removal of brazing scale from typewriter parts prior to nickel plating is outlined. Test data are tabulated.—INCO. 9969

5.9.2, 8.9.1

Cleaners for Airliners. B. L. SOUTHWICK. Paper before Chem. Specialties Mfgrs. Assoc. Symposium, 41st Ann. Mtg., New York, December 7, 1954. *Soap & Chem. Specialties,* **31,** No. 1, 44-45, 177 (1955) January.

Covers compounds used on exteriors and interiors, engine cleaning materials and plant maintenance materials. Prevention of corrosion is of major importance. Emulsion type cleaners diluted with a petroleum solvent and abrasive type cleaners are used on aluminum skin or covering. A water rinsable type paint stripper is employed to remove corrosive carbon and lead oxide deposited on exterior wing and engine nacelles by exhaust gases. Engine cleaner must remove carbon and sludge deposit without being corrosive to aluminum, magnesium and steel alloys. Mounts and other steel parts that accumulate burned-on oil are placed in a strong hot caustic solution. Plant floors are cleaned with an alkaline type cleaner since harsh caustic type cleaners create dust that is corrosive to aluminum surfaces.—INCO. 9813

5.9.2

Suggested Guide to Laboratory Metal Cleaning. J. C. HARRIS, W. STERICKER AND S. SPRING. *ASTM Bull.,* No. 204, 31-34 (1955) Feb.

The factors involved in cleaning procedures for removing various types of contaminating substances from metal surfaces are listed, with fifteen tests (with literature references) for determining metal cleanliness.—BNF. 10076

5.9.2, 1.6

Industrial Detergency. W. W. NIVEN, JR., Editor. Book, 1955, 340 pp. Reinhold Publishing Corp., 430 Park Avenue, New York.

Chapter 10 of this book (pp. 254-274) Metals Industries covers nature of dirt or soils; types of cleaners and cleaning equipment; soak tank cleaning; spray cleaning; electrolytic cleaning; vapor degreasing; barrel cleaning; use of ultrasonic waves; properties and applications of different cleaning agents; control of cleaning processes; short notes on methods for various steels, aluminum, copper, magnesium and zinc alloys. On p. 46 there is a passing reference to the use of inhibitors in detergent solutions; on pp. 315-318 there is a discussion of problems in cleaning railway car bodies (mentioning steel and aluminum surfaces) owing to corrosion from unsuitable cleaning agents; cleaning of automotive vehicles is dealt with on pp. 321-324.—BNF. 10601

5.9.2, 5.8.2

Reduction of Attack of Acid on Zinc By Inhibitors. (In German.) W. WIEDERHOLT. *Werkstoffe u. Korrosion,* **6,** No. 5, 247-248 (1955) May.

In order to remove dangerous corrosion products at local perforations in galvanized steel, or to prepare zinc surfaces for painting, treatment with acid is used. It is shown that inhibition by quinoline greatly reduces attack of dilute acids on zinc.—BNF. 10344

5.9.2, 6.4.2

Developments in the Chemical Brightening of Aluminium. (In German.) R. LATTEY AND H. NEUNZIG. *Metalloberflache,* Ser. A, **9,** No. 7, 97A-103A (1955) July.

An investigation of the Alupol and the Erftwerk processes. In each case the optimum composition of the solution, and the brightening attainable with diminishing purity of aluminum (99.993 to 99.56 percent) are examined. For superpure aluminum and alloys the Erftwerk process is superior, but inferior for less than 99.9 percent aluminum.—BNF. 10844

5.9.3

Cleaning with Ultrasonics. F. W. HIGHTOWERS. *Metal Progress,* **68,** No. 1, 99-104 (1955) July.

Applications of ultrasonic cleaning, particularly where surfaces are inacces-

sible or must be scrupulously clean as for plating or adhesive bonding. Choice of frequency and intensity, type and choice of transducer materials (quartz, barium titanate); solvents, equipment and generators; costs.—BNF. 10801

5.9.4

Contribution to the Theory of Electropolishing. J. F. NICHOLAS AND W. J. McG. TEGART. *J. Electrochem. Soc.*, **102,** No. 4, 93C-94C (1955) April.

Points out that the theoretical results obtained by Wagner can be reached without making any assumptions about the mechanism of the polishing process. The experimental results obtained by Edwards in work done at Brit. Non-Ferrous Metals Research Assoc. are used as an example.—BNF. 10596

5.9.4

The Effect of Chromic and Chromic-Phosphoric Acid Rinse Solutions on the Durability of Paint Coatings. J. Doss. Rock Island Arsenal. *Org. Finishing*, **16,** No. 6, 7-13 (1955) June.

Phosphate coated steel panels were rinsed in various concentrations of chromic acid, chromic-phosphoric and phosphoric acid solutions, spray painted with three types of paint and subjected to water immersion and salt spray corrosion tests. Panels rinsed in solutions containing 30 oz. chromium trioxide/100 gal. or 16 oz. chromium trioxide plus 16 oz. phosphoric acid/100 gal. exhibited less corrosion after salt spray and fewer paint blisters after water immersion. Panels rinsed in 32 oz. phosphoric acid/100 gal. rinse showed considerable corrosion resistance in water immersion tests but had most corrosion products and paint flaking in salt spray test. Photographs of test panels.—INCO. 10528

5.9.4

Anodised Coatings: What They Are, How They Behave. Parts I, II. C. C. COHN. *Iron Age*, **175,** Nos. 21, 22, 91-94, 95-98 (1955) May 26, June 2.

Part I. Anodizing aluminum and aluminum alloys: formation of film, its appearance and structure; effect of different electrolytes; effect of pore size on life of coating. Part II. Hardness and thickness of anodic film; measurement of thickness; stresses and cracks; attack by chlorine ions.—BNF. 10509

5.9.4

The Anodic Treatment of Aluminium in Sulphuric Acid Solutions. R. C. SPOONER. *J. Electrochem. Soc.*, **102,** No. 4, 156-162 (1955) April.

Appearance, coating weight, metal loss, coating ratio, rate of chemical dissolution of the coating, sealing weight gain, color rating of dyed panels and apparent coating density for specimens of 99.87 percent aluminum anodized for 2-60 min. in 5-50 percent sulfuric acid at 10-50C and 1.7-6.2 amp./dm.^{2}—BNF. 10364

5.9.4, 6.3.11, 6.3.19

1) Mechanism of Electropolishing of Silver. 2) Mechanism of Electropolishing of Zinc. (In Russian.) A. T. VAGRAMYAN AND A. P. POPKOV. 1) *Doklady Akad. Nauk, SSSR*, **102,** No. 2, 297-300 (1955) May 11. 2) *ibid.*, **102,** No. 3, 547-549 (1955) May 21.

The anodic processes in the electropolishing of silver in $KAg(CN)_2$ and of zinc in zinc sulfate solutions were studied by obtaining the polarization curves.—BNF. 11030

5.9.4, 6.4.2

Electrochemical Structure of the Surface of Electropolished Aluminium. (In Russian.) P. V. SHCHIGLOEV AND G. V. AKIMOV. *Doklady Akad. Nauk SSSR*, **100,** No. 3, 499-502 (1955) Jan. 21.

Active places on the surface were detected by cathodic polarization in cupric sulfate solution. The variation in the number of active places on electropolished specimens with increasing polishing time was studied for acid and alkaline (sodium carbonate/sodium phosphate) solutions. Also mechanically polished aluminum for comparison.—BNF. 11020

5.9.4, 6.4.4

Nature of Films Obtained by Anodic Oxidation of Magnesium and Its Alloys in Chromic Acid Solutions. (In Russian.) B. A. POSPELOV. *J. Applied Chem.*, USSR (Zhurnal Prikladnoi Khimii), **28,** No. 7, 748-750 (1955) July.

Black and brown coatings are described. 2 tables, 2 references.—ATS. Translation available: Assoc. Tech. Services, P. O. Box 271, East Orange, New Jersey. 10946

5.11, 6.5

Choice of Materials in Connection with Corrosion. (In Dutch.) C. VAN DUIJN. *Polytechn. Tijdschr.*, **10,** No. ½, 32a-35a (1955).

Van Duijn reviews the suitability of a number of metals and alloys for various applications likely to be affected by corrosive agents.—MA. 11032

6. MATERIALS OF CONSTRUCTION

6.1 General

6.2.2

Low-Expansion Cast Iron. H. BROWN. Hunt-Spiller Mfg. Corp. *Machine Design*, **27,** No. 6, 175-177 (1955) June.

Properties and design characteristics of a nickel cast iron capable of holding precision dimensions under local heating conditions are discussed. Castings of this 36 percent nickel alloy, called Min-o-var, have been successful in precision machines. In addition to a low coefficient of expansion, Min-o-var has other advantageous characteristics such as gall resistance, vibration-damping capacity, machinability of graphic cast iron, and good corrosion resistance. Properties are listed. Graph.—INCO. 9958

6.2 Ferrous Metals and Alloys

6.2.1, 1.6, 3.7.2

Titanium in Iron and Steel. G. F. COMSTOCK. Book, 1955, 294 pp. John Wiley & Sons, Inc.

Monograph on the effect of titanium on steel and cast iron.—INCO. 9968

6.2.2, 3.4.6

Oxygen in Gray Cast Iron. R. C. WILLIAMS AND H. W. LOWNIE, JR. *Battelle Tech. Rev.*, **4,** No. 5, 58-59 (1955) May.

Recent study of three flake-type cast irons and one containing nodular graphite for a period of one year after production showed that gray cast iron can absorb oxygen when stored under average atmospheric conditions. This explains high oxygen contents (up to 0.047 percent) often reported in analyses.—INCO. 9910

6.2.2, 3.8.2, 3.6.8

The Electrochemical Behavior, Including Hydrogen Overvoltage, of Iron in Acid Environments. MILTON STERN. *J. Electrochem. Soc.*, **102,** 609-616 (1955) Nov.

Corrosion rate of pure iron in deaerated acid media was studied as a function of pH. Rate was found to be essentially independent of pH over the range 1-4% sodium chloride. Potential and polarization measurements are used to explain this behavior. Method is described for calculation of corrosion rates from electrochemical measurements alone. Limitations and environmental conditions required for this method are discussed. Hydrogen overvoltage on pure iron in 0.1M citric acid and 0.1M malic acid is

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shown graphically. Diagram and graphs. —INCO. 10999

6.2.2, 3.8.4

Determination by Electron Diffraction of the Constitution of Oxide Films Formed on Iron. JEAN MOREAU AND JEAN BARDOLLE. *Compt. rend.*, **240,** No. 5, 524-526 (1955).

The constitution of oxide films showing interference colors and formed at the surface of iron in air at 250-700C is similar to that of thick films prepared in conditions of severe oxidation. Further, the oxide α-Fe_2O_3 tends to orient itself with the ternary axis of the perpendicular rhombohedron at the surface of the specimen.—MA. 10895

6.2.3, 3.7.2, 3.7.3

Diffusion of Arsenic in Steel. D. S. KAZARNOVSKII. *Doklady Akad. Nauk SSSR*, 100, No. 6, 1073-1075 (1955).

Study of the ability of arsenic to diffuse in 5 high-carbon structural steels (O.H.) containing 0-0.313% arsenic. Particulars on composition of steels, data on five different heat treatments given to the arsenic-containing steels, degree of banding in specimens as function of their arsecnic content and results of micrographic analysis and conclusions drawn as to the best way of improving the structure and properties of arsenic-containing high-carbon steels are included. —INCO. 10939

6.2.3, 4.2.4

Atmospheric Corrosion of Mild Steel in a Chemical Plant. R. I. ZIMMERER. *Corrosion*, **11,** No. 6, 17 (1955) June.

Duration of wet conditions, chemical composition of atmosphere and composition of corroding metal listed as factors affecting atmospheric corrosion. Rise in cumulative corrosion rates attributed to breakdown of rust scale after it had become too heavy to maintain its continuity. Economics of corrosion protection.—BL. 11063

6.2.5

Selection and Application of Stainless Steel in the Chemical Process Industries. Am. Soc. Metals Ctte. on Stainless Steel in Chemical Uses. *Metal Progress*, **68,** No. 2-A, 37-49 (1955) August 15.

Supplements section on stainless steels in 1948 ASM Metals Handbook. Types of corrosion of stainless steel (austenitic and ferritic), design and fabrication. Corrosion data are set out in great detail, with detailed individual discussions on behavior of various kinds of stainless steels in a large variety of chemicals, fine chemicals, pulp and paper industry and food industry.—BNF. 10903

6.2.5

Progress in the Manufacture and Applications of Stainless Steel Castings in the Chemical Industry. F. POLZGUTER. *Werkstoffe u. Korrosion*, **6,** 375-385 (1955) Aug.-Sept.

Discussion of applications of various cast stainless steels and cast alloys in the chemical industry includes Remanit 2890, 2890 Mo, 2810, 2810 Mo, 2804 and 2804 Mo, and Hastelloy A, B and C. Some creep data are given for high-alloy steels ATS 5, ATS 15, ATS 12, S 71 and ATS specifications (compositions given). Most are nickel-chromium, chromium, or nickel-chromium-molybdenum steels; ATS 5, ATS 12 and S 71 are nickel-chromium-cobalt alloys.—INCO. 10962

6.2.5, 3.7.2, 3.2.2

Some Peculiarities of Intercrystalline Corrosion of Austenitic Stainless Steel. (In Russian.) A. V. SHREIDER. *J. Applied Chem., USSR* (Zhurnal Prikladnoi Khimii), **28,** No. 6, 608-615 (1955) June.

Tendency towards corrosion found in certain zones of several batches from one heat, several sheets from one batch and individual areas of same sheets. Tests were done in various corrosive electrolytes. As a result of extensive tests changes in titanium and carbon content recommended for reduced corrosion. 5 figures, 11 references.—ATS. Translation available: Assoc. Tech. Services, P. O. Box 271, East Orange, New Jersey. 11017

6.2.5, 3.7.3

The Welding of Type 347 Steels. The Results of Nitric Acid and Copper Sulfate-Sulfuric Acid Tests on Modified Type 347 Weld Deposits. LORIN K. POOLE. Arcos Corporation. U. S. Atomic Energy Commission Pubn., NYO-3499, July, 1955, 23 pp.

Five variations in composition were tested to determine suitability for replacing standard composition. Micrographs, tables. 7 references.—BTR. 10956

6.2.5, 5.9.4

Protecting Stainless Steels from Corrosion by Anodic Polarization. (In Russian.) N. D. TOMASHOV AND G. P. CHERNOVA. *Doklady Akad. Nauk SSSR*, **104,** No. 1, 104-107 (1955) Sept. 1.

Anodic polarization curves of chromium-nickel steels in various sulfuric acid concentrations at 25C. Effectiveness of anodic oxide coating against corrosion. Table, graphs. 10 references.—MR. 11072

6.3 Non-ferrous Metals and Alloys—Heavy

6.3.2, 6.3.19, 3.8.2

Study of the Corrosion of Cadmium and Zinc by the Polarographic Method. (In Russian.) A. IA. SHATALOV. *J. Applied Chem.*, USSR (Zhurnal Prikladnoi Khimii), **28,** No. 9, 944-949 (1955) Sept.

Corrosion in chloride and other solutions of pure and technical cadmium and zinc; effect of pH on the potential of the metal; time factor in corrosion. Graphs, tables. 7 references.—BTR. 11008

6.3.6

Comparative Corrosion Tests of Some Condenser Tube Materials and Other Copper Alloys in Salt Water. T. OTSU. *Sumitomo Metals*, **7,** No. 3, 22-32 (1955) July.

Experiments to study the comparative corrosion resistance of condenser tube materials and other copper alloys were made with an immersion corrosion test in contaminated brackish water, a salt spray test, an alternate immersion test and a jet impingement test in 3% sodium chloride solutions. Admiralty is superior to Cupronickels in contaminated brackish water, but is not so good in clean salt water. Albrac (aluminum brass) is superior to the other materials tested in clean and contaminated salt water. The erosion resistance of Albrac is slightly inferior to 10% cupronickel. Cupronickels corroded more in contaminated brackish water than the other materials tested, but in clean salt water their resistance is improved. Erosion resistance is relatively good and that of 10% cupronickel is best. Cartridge, Muntz and Naval brass are generally more resistant than copper and silicon-bronze in salt water but they suffer dezincification.—INCO. 10927

6.3.6

Studies on Corrosion at Power Generating Stations Using Acidic River Water (12th Rept.). On the Corrosion of Copper Alloys. S. SHIMODAIRA AND Y. SAWABA. *J. Japan Inst. Metals*, **19,** No. 2, 86-89 (1955) Feb.

Corrosion rate of copper alloys by dilute aqueous solutions of sulfuric acid has been measured. Corrosion rate increases nearly in proportion to relative velocity in the range of low speed, but becomes gradually constant as the velocity increases. As the concentration of hydrogen ions increases, corrosion rate increases. Corrosion is mainly controlled by the diffusion and the adsorption of dissolved oxygen on the copper alloys.—JSPS. 11019

6.3.6, 3.2.2, 3.7.2

On the Dezincification of Brass Castings. M. SUGIYAMA AND S. UEDA. *Corrosion Engineering*, **4,** No. 2, 74-78 (1955) April.

The object of the work was to determine the effect of some added elements to 65/35 and 60/40 brass castings on their dezincification properties in sodium chloride solution.

It was demonstrated that the quantitative measurement of dezincification could be performed by colorimetric determination using the photometer and that tin was most effective as an alloying element to prevent dezincification, manganese and aluminum were slightly effective and iron was assessed as an undesirable constituent.

The 65/35 cast plain brass which consisted of α-monophase had immunity to dezincification phenomena but showed typical chemical corrosion.

Micrographic examination of corroded surface revealed that the β-phase was locally attacked at the first stage of corrosion in α/β or β/γ alloy systems, then the dissolved copper was redeposited on the copper rich cathode which was formed on β-phase.—JSPS. 10995

6.3.6, 7.6.4, 8.9.4

Anti-Corrosive Copper Alloys for Boiler Parts of Steam Locomotives. (In Japanese.) TOSHIO SAITO, KAZUO OHYAMA AND YORIHISA YOSHINARI. *J. Railway Engineering Research* (Japan), **12,** No. 15, 371-387 (1955) Aug. 10.

New machining method will permit use of naval brass which exhibits absence of crystallization compound of base metal other than copper and great hardness. Micrographs, photographs, graphs, diagrams, tables.—BTR. 10976

6.3.20

Vacuum Induction-Melted Zirconium and Zirconium Alloys. H. A. SALLER, R. F. DICKERSON AND E. L. FOSTER, JR. Paper before Vacuum Metallurgy Symp., Electrochem. Soc., Electrothermics & Metallurgy Div., Boston, October 6-7, 1954. Vacuum Metallurgy Symposium, Electrochem. Soc., 1955, 49-60.

Study of vacuum induction melted sponge zirconium, iodine zirconium machine chips, Zircaloy 2 and zirconium alloys containing 2.5 and 5% tin. Melting process is described. Hardness at room temperature and up to 800 C, drawability, electrical resistance, corrosion behavior in hot water and steam and tensile properties were determined. Microstructures were studied and at-

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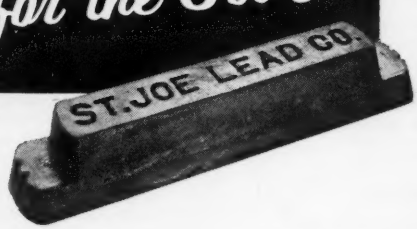

A method of protecting lead-lined vessels under high temperature conditions is to cover the metal with an inner lining of special acid-resistant brick. The installation shown above is a sulfuric acid concentrator, 16 ft. in diameter and 24 ft, high. Some 19 tons of chemical lead were used in lining the vessel. This type of construction is used commonly in the 450°F range and has been used at higher temperatures. The brick lining provides a temperature gradient to insulate the lead. Since no aggregate material can be entirely impervious to seepage, the corrosives leaking through are stopped by the lead lining and thus prevented from destroying the steel supporting structure. *Photo courtesy Chemsteel Construction Co., Inc.*

TYPICAL ANALYSIS OF ST. JOE CHEMICAL LEAD

Silver	.0100%	Arsenic-Antimony-Tin Combined	.0002%
Copper	.06	Cadmium	.0002
Bismuth	Nil	Cobalt & Nickel	.0046
Zinc	.0001	Lead by difference	99.92+
Iron	.0001		

Among the common metals, lead has no equal in its value to the chemical industry as a construction material for handling and controlling corrosives. The metal's utility in this field is well documented by a wealth of available performance records. The protection afforded by lead is the end-result of an inherent chemical property which is unique with the metal. Exposed to most corrosives, lead automatically forms upon its surface an insoluble, tightly adherent film of salts which henceforth acts as an effective barrier against further corrosion. The uncommon property of the common metal lead to forge its own protective armor is the reason why more than one-third of all the lead consumed annually in this country is used primarily for its resistance to corrosion.

St. Joe Chemical Lead is the most extensively used brand of lead in the chemical industries. Hundreds of thousands of tons are now in use—especially where operating conditions are severe. The metal is an exclusive product derived from the huge ore bodies of southeast Missouri which have been owned and operated by this Company since 1865. Owing to the unusual nature of these ores, there is present in the lead smelted from them a combination of copper and small amounts of other elements which produces a grade of lead particularly immune to the attack of most corrosives. At the same time, this natural chemical lead has a lower creep rate and a higher resistance to fatigue failure than lead produced from any other ores.

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tempt made to correlate these with the properties of the materials. Composition for Zircaloy 2 is given as 1.5% tin, 0.12% iron, 0.10% chromium, 0.05% nickel, balance zirconium. Tables, graphs. —INCO. 10981

6.4 Non-ferrous Metals and Alloys—Light

6.4.2, 3.7.3

Relationship Between Metallographic Structure and Susceptibility to Inter-Crystalline Corrosion of a Binary Aluminum-5% Copper Alloy. (In Italian.) M. PAGANELLI. *Alluminio*, **24**, No. 4, 335-343 (1955) July-August.

Aluminum alloy samples containing 5.02% copper, 0.010 silicon and 0.003% iron were heat treated at 530 C and artificially aged at 160-190 C, or were permitted to age naturally. The mechanical characteristics developed as a function of time were determined and recorded. The samples were then subjected to rapid corrosion and stress corrosion testing. In the first case immersion in a 3% sodium chloride plus 0.25% hydrochloric acid solution for 2½ hours was applied and the amount of hydrogen liberated was volumetrically determined. The stress corrosion test was conducted in a solution of 3% sodium chloride plus 0.1% hydrogen peroxide. Experimental results of both are tabulated. Based on a subsequent micrographic study of the samples it is concluded that: 1) naturally aged alloy was only liable to corrode when exposed for a long duration to highly aggressive media; 2) artificial ageing, due to the structural inhomogeneities developed, promoted corrosion at the zones of preferred precipitation; 3) if the alloy was under-aged the intercrystalline corrosion appeared at the grain boundaries and was highly penetrating; 4) if the sample had reached its maximum mechanical strength the intercrystalline corrosion developed along the slip planes and its penetrating power appeared to be diminished; 5) if the alloy was over-aged, the precipitation extended to the entire grain matrix in solid solution reducing potential differences and thus also diminishing the liability to corrode. In order to reduce susceptibility to corrosion of alloys of this type it is recommended to increase the duration of artificial ageing slightly beyond the point of maximum mechanical strength.—ALL. 10930

6.4.2, 3.7.3

Stabilization Heat Treatment of Aluminium-5% Magnesium Alloys for the Purpose of Counteracting the Effects of Low Temperature Heating. (In French.) ANDRE GUILHAUDIS. *Rev. Aluminium*, **32**, No. 224, 795-801 (1955) September.

In this concluding part of two articles on stabilization heat treatment of aluminum-magnesium alloys applied to prevent intercrystalline corrosion due to low temperature heating, three more procedures are discussed: 1) it is demonstrated that an interrupted slow cooling, that is a slow cooling (4 C/hour) from the annealing temperature to 160-175 C produces the same effects as a slow cooling prolonged until reaching ambient temperature; 2) the method of tempering in series is explained which consists in consecutive annealing in two furnaces, the second being heated to a lower than ordinary annealing temperature, followed by cooling at ambient temperature. It is pointed out that the rapidity of this latter method, as compared to slow cooling, constitutes a distinct advantage in the industrial practice; 3) finally the procedure of inhibiting annealing is studied, and the time and temperature factors of this second annealing, subsequent to a cooling at room temperature after the first annealing at 400 C, are investigated. The experiments conducted comprising different methods of heat treatments under various conditions and the pertinent tests for intercrystalline corrosion demonstrated that the heterogeneizing action of the inhibitive treatments discussed reduces the sensitivity of aluminum-magnesium alloys to intercrystalline corrosion. The application of the treatments studied seems to be justified by the observed fact that an alloy containing 5.59% magnesium treated by the slow cooling method and subjected to prolonged heating at 75 and 125 C exhibited less sensitivity to intercrystalline corrosion than a non-stabilized Al-5.15% Mg alloy.—ALL. 10931

6.4.2, 3.8.2

The Nature of Aluminum as a Cathode. M. J. PRYOR AND D. S. KEIR. *J. Electrochem. Soc.*, **102**, No. 10, 605-607 (1955) October.

Tests to determine the distribution of effective cathodic areas were carried out on cold rolled and annealed aluminum (both etched in ½% hydrofluoric acid), iron and magnesium (etched in 2% nital), tin (etched in 5% nital), copper (etched in 1:1 nitric acid), lead (etched in concentrated nitric acid), and zinc (etched in 20% chromic acid plus 7.5% sodium sulfate). All specimens had an area of 10 sq. cm. and were stored in dry air for 24 hr. after etching to permit the formation of air-formed oxide

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films. The tests used to investigate the initial distribution of cathodic areas were: a) Cathodic treatment of the specimen in normal sodium chloride containing one drop of phenolphthalein at a current of 1 microamp./sq. cm. of specimen using a platinum anode. The distribution of the alkali formed during the cathodic reaction indicated the position of the cathodic areas. b) Cathodic treatment of the specimen for a minute in normal sodium chloride containing 0.1% of cupric sulfate at a current of 1 microamp./sq. cm. of specimen using a platinum anode. Deposited copper on the specimen also gave an indication of the distribution of the cathodic areas which could be photographed readily. c) Cathodic treatment in normal sodium chloride containing sodium molybdate at a current of 1 microamp./sq. cm. The distribution of the reddish-brown permolybdate indicates the distribution of

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TP-1 Report on Field Testing of 32 Alloys in the Flow Streams of Seven Condensate Wells (Pub. 50-3) NACE members, $8; Non-members, $10 per Copy.

T-1A Survey of Corrosion Control in California Pumping Wells. A Report of T-1A on Corrosion in Oil and Gas Well Equipment, Los Angeles Area. Pub. 54-7. Per copy, $.50.

T-1C Current Status of Corrosion Mitigation Knowledge on Sweet Oil Wells. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion. Per copy, $.50.

T-1C Field Practices for Controlling Water Dependent Sweet Oil Well Corrosion. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion, Compiled by Task Group T-1C-1 on Field Practices. Pub. No. 56-3, Per Copy $1.00

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T-3A Some Corrosion Inhibitors—A Reference List. A Report of T-3A on Corrosion Inhibitors. Publication 55-3. Per Copy $.50.

T-3E Tentative Procedures for Preparing Tank Car Interiors for Lining. A Report by NACE Task Group T-3E-1 on Corrosion Control of Railroad Tank Cars. Per Copy $.50.

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TP-12 Report on Electrical Grounding Practices. Per Copy $.50.

TP-19 Corrosive Effects of Deicing Salts—A Progress Report by Technical Practices Committee 19. *Corrosion*, January, 1954, issue. NACE members $.50; Non-members $1 per copy.

hydrogen peroxide on zinc and aluminum cathodes. In all the tests the applied current flowed as soon as the specimen came in contact with the solution. Results showed that iron, copper, magnesium, zinc, tin and lead all carrying air-formed oxide films, act as effective cathodes over most of their surfaces. However, aluminum, when covered with an air-formed oxide film, acts as an efficient cathode only at small isolated points. On cold-rolled aluminum these appear to be randomly distributed over the surface of the specimens. On annealed aluminum the average size of the spots of copper is smaller than on cold rolled aluminum, but a distinct correlation between the grain boundaries and the copper deposition is apparent. These results may be interpreted as meaning that the electronic resistance of the air-formed oxide film on aluminum, unlike those of the other metals studied, is so high that it prevents the migration of electrons to the film/solution interface except at small "weak" points of low electronic resistance. Thus, instead of the cathodic reaction taking place at low current density over most of the surface it takes place at a much higher current density over a small portion of the surface.—ALL. 10988

6.4.2, 5.9.4

Contribution to the Surface Condition of Semi-Finished Aluminium Products Before Anodizing. (In German.) H. A. J. STELLJES. *Metall,* **9,** No. 17/18, 748-751 (1955) Sept.

Describes and discusses various frequent surface defects and methods of obviating or improving them. Defects arising in casting, hot and cold rolling; purity of basis metal; "reticulation" and its relation to structure of ingots and effect of fine grain and of homogenization in extrusion billets on anodizing behavior. Cladding with pure aluminum (99.99%), which gives the best surface on anodizing.—BNF. 11070

6.4.2, 6.6.5, 7.7

A Report of an Unusual Case of Corrosion of Aluminum in Concrete. T. E. WRIGHT. Paper before Montreal Corrosion Symposium, Sponsored by NACE (Can. Region), Protective Coatings Div. of Chem. Inst. of Canada, and National Research Council Associate Comm. on Corrosion Research and Prevention, September 15, 1955. *Engineering J.,* **38,** 1357-1362 (1955) October.

Aluminum electrical conduit was corroding severely in some places even though embedded in dry concrete floors and in accordance with recommended procedure. Corrosion was found to be due to calcium chloride in concrete mix, together with presence of galvanic currents from contact with embedded steel. —INCO. 11062

6.4.2, 8.9.5, 3.7.3

Aluminium in Shipbuilding. *Welding and Metal Fabrication,* **23,** Nos. 6, 8, 194-223, 299-306 (1955) June, August.

Includes: The Present Position of Aluminum in Shipbuilding, E. G. West (pp. 194-203, 299-306; 28 references); A Review of Aluminum Alloys as Engineering Materials, J. R. Handforth (pp. 204-210); Aluminum in Norwegian Shipbuilding: Extensive Use of Metal-Arc Welding (211-216); Fabricating the Aluminum Superstructures of s. s. *Sunrij,* H. G. Jarman (pp. 217-220); Sigma Welding in Ship Construction: Automatic Assembly of Light Alloy Structures, D. B. Tait (pp. 221-223).—BNF. 11045

6.4.3

Direct Stress Fatigue Tests of Beryllium. W. P. WALLACE AND R. H. WALLACE. Calif. Res. & Dev. Co. *Light Metal Age,* **13,** No. 10/11, 19 (1955) October.

Stress-strain curve and direct stress S-N curve for beryllium are given. Data presented include 56,700 psi tensile strength, 52,400 psi yield strength, 1.1% elongation (in 2 inches) and 31,000 psi endurance limit.—INCO. 11038

6.4.4, 3.8.2

Corrosion Reactions of Magnesium. Part VII. GORO WADA. *J. Chem. Soc. Japan,* **76,** No. 1, 97-101 (1955) Jan.; *Chem. Absts.,* **49,** No. 19, 13058 (1955) Oct. 10.

Corrosion of magnesium in two molecular potassium chloride containing metal chlorides more noble than magnesium such as cobalt, copper, cadmium, iron, zinc and tin was studied at 30 C. In the initial stage of the reaction metal ions deposit on magnesium and in the latter stage local cell is formed and magnesium dissolves with constant velocity. The rate of the reaction in the latter stage is in the following order: cobalt >> copper >> iron > zinc > cadmium > tin >> mercury.—ALL. 11035

6.4.4, 3.8.2, 3.4.4

Corrosion Reactions of Magnesium. Part VIII. Aqueous Solutions Containing Metal Ions. Energy of Activation. G. WADA. *J. Chem. Soc. Japan,* **76,** No. 2, 187-190 (1955) Feb.

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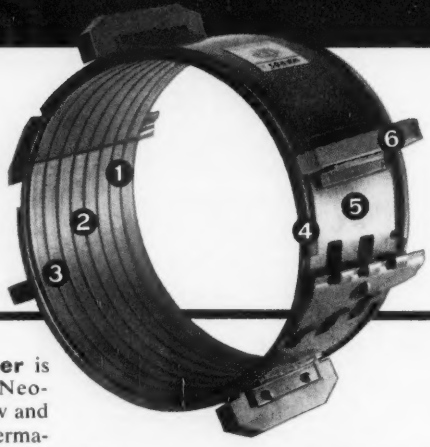

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corrosion reactions of magnesium in aqueous solutions of potassium chloride containing cobaltous chloride, cupric sulfate and zinc sulfate at various concentrations were measured by the usual methods and the following results were obtained.

Activation energy increases as concentration increases.

Activation energy in the case of cobalt is higher than in the cases of copper and zinc.

Hydrogen evolution on the cathodic areas of magnesium surface is rate-determining step of the corrosion reaction.—JSPS. 11037

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1, 6.4.2

Engine Bearings of Aluminum. D. B. Wood. Aluminum Co. of Am. *Ry. Locomotives & Cars*, 129, No. 7, 47, 49 (1955) July.

Solid aluminum bearings are unique as the only mono-metal bearings that can operate under heavy or high-duty requirements. Laboratory and service tests have indicated that with proper design and installation, they will take as much or more abuse as other bearings. Basic advantages of aluminum bearings include excellent resistance to corrosion, ability to carry heavy loads, high thermal conductivity and adaptability to various designs and types of applications. Points for consideration in designing aluminum bearings are discussed.—INCO. 11060

7.1, 7.2, 8.9.2

Corrosion in the Motor Car. Part 4. Bearings and Exhaust Valves. Z. S. Michalewicz. *Corrosion Technology*, **2**, No. 11, 334-338 (1955) Nov.

Reviews causes of bearing corrosion (excessively high and abnormally low engine temperatures, inferior lubricant, pressure corrosion and sulfide attack) and discusses corrosion resistance of various bearing materials including cadmium alloys, copper-palladium alloys, silver, bronzes, alkali-hardened lead and aluminum alloys. Causes for corrosion in exhaust valves, and corrosion resistance of valve steels classified as ferritic (Silcrome 1 and Silcrome XB), austenitic (En 54, En 55 and DTD 49B) and sigma-precipitate (XCR and XCT) are reviewed. Nimonic 75, 80 and 90, Inconel X and TPM are used when exceptional corrosion-resistance and high-temperature properties are requried. Coating valve head with Brightray, Stellite 6 and F and Nichrome is mentioned. 17 references, photomicrographs. —INCO. 10907

7.4 Heat Exchangers

7.4.2, 3.7.3

Studies on the Extraordinary Corrosion of the Copper Tubes of a U-Fin Heater. K. Okano, Y. Kitamura and R. Takahashi. *Corrosion Engineering*, **4**, No. 1, 27-30 (1955) Feb.

A U-fin heater used as an air heater for drying powder materials was damaged due to corrosion of the copper heating tubes. As the result of experiments, it was concluded that the corrosion was caused by the adhesion of solder to inner surface of the copper tube. To remove the solder, electrolytic and chemical methods were examined. Some methods appear promising.—JSPS. 10922

7.6 Unit Process Equipment

7.6.6, 8.5.3

Design Features Affecting Digester Corrosion. L. G. Pfeiffer, M. A. Scheil and E. H. Schmidt. Paper before TAPPI, 10th Eng. Conf. Tech. Assoc., Houston, November 7-9, 1955. *Tappi*, **38**, No. 11, 652-659 (1955) November.

Presentation of facts brought forth during roundtable discussion of TAPPI Corrosion Committee (New York, Feb. 20, 1955). Digester circulation system, pedestal versus skirt type supports for digesters, design of internal projections and means of baffling to protect digester walls from streak corrosion, surface preparation of carbon steel and alloy lined digesters and stress relief and radiography of sulfate digesters are topics under consideration. Preferential corrosion attack takes place in specific areas due to nonuniform circulation. Chief factors affecting circulation are uniformity of chip size, chip loading, chip packers, liquor volume, steam inlets and digester relief. Skirt-type supports eliminate localized corrosion fatigue caused by pedestal supports. Scale

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deposits, pitting and corrosion cracking of Type 316 and 318 clad sulfite digesters are shown.—INCO. 10945

7.6.6

Experiments With Digester Corrosion Variables. E. W. HOPPER AND J. B. MORRISON. Paper before TAPPI, 39th Ann. Mtg., New York, Feb. 15-18, 1954. *Tappi*, **38**, No. 1, 8-17 (1955) January.

Paper includes a study covering the variables in chemical analyses and physical characteristics of carbon steel samples taken from plates which have gone into kraft digester service, a study of the corrosion effect of variables in white liquor compositions on different types of steel under varying conditions and an attempt to determine effect on corrosion rates of protective films built-up on steel by cathodic protection. Results indicate that these are factors which may be contributory to the increasing rate of attack and are worthy of continued investigation.—INCO. 10369

7.6.6, 1.7.1

Five Year Investigation of Digester Corrosion by the TAPPI Chemical Engineering Committee. J. R. LIENTZ, S. J. BAISCH, H. O. TEEPLE AND N. SHOUMATOFF. Paper before TAPPI, 40th Ann. Mtg., N. Y., February 21-24, 1955. *Tappi*, **38**, No. 6, 373-378 (1955) June.

Over-all complex alkaline digester corrosion problem is considered from the standpoint of its economic importance, its theoretical background and its practical control.—INCO. 10446

7.6.6, 8.5.3

Comparative Analysis of Digester Corrosion Measurements—Tappi Digester Corrosion Subcommittee Summary Report No. 2. N. SHOUMATOFF AND H. O. TEEPLE. Paper before Tappi, 9th Eng. Conf., Philadelphia, October 18-21, 1954. *Tappi*, **38**, No. 4, 202-207 (1955) April.

An industry-wide survey of alkaline digester corrosion is concluded with additional data and re-examination of data previously used. Statistical errors of thickness measurement in different mills are compared. Localized attack is analyzed in relation to liquor circulation and heating. Revised estimates of prevalent corrosion rates for carbon steels and alloys (including Inconel and stainless steel clad alloys) are presented. Corrosion rate trends and fluctuations are investigated and compared with process variables. 13 references.—INCO. 10413

7.6.7

Filters. J. M. CHALMERS, L. R. ELLEDGE AND H. F. PORTER. *Chem. Eng.*, **62**, No. 6, 191-216 (1955) June.

Various types and varieties of filters for separation operations are constructed of cast iron, steel, cast Ni-resist or bronze and fabricated stainless steel or Monel. Diagrams.—INCO. 10736

7.7 Electrical-Telephone and Radio

7.7, 5.3.2, 3.6.4

Rhodium Plating Electrical Plugs. *Electroplating & Metal Finishing*, **8**, No. 7, 257 (1955) July.

Contact corrosion on brass sockets which come into electrical contact with phosphor bronze plugs can be reduced by rhodium plating the plugs. A nickel, bright nickel, or silver undercoat may be suitable. Deposit of 0.1 mil is suggested for outdoor use, while 0.015-0.025 mil will generally be sufficient for indoor service. Best rhodium plating solutions are sulfate, phosphate or sulfate-phosphate bath.—INCO. 10502

7.7

Power and Control Cables for Steel Mills. E. D. YOUMANS. Okonite Company. *Iron Steel Engr.*, **32**, No. 9, 81-87; disc., 87-89 (1955) September.

Insulation, sheathing and installation of low, medium and high voltage power and control cables for underground, aerial and indoor service. Majority of cables are rubber-insulated and neoprene-sheathed. Lead sheath corrosion is corrected by application of neoprene coating. interlocked copper, bronze or stainless steel tape is used for aerial installations where corrosion might be encountered. —INCO. 11061

7.10 Other

7.10, 4.2.3, 8.2.2

The Design and Comparative Costs for High Stacks. E. J. STANKIEWICZ. Paper before Am. Soc. Mech. Engrs., Ann. Mtg., New York, November 28-December 3, 1953. *Combustion*, **26**, No. 8, 51-56 (1955) February.

Review of problems brought about by improved dispersion of flue gases from steam generating power stations by increasing stack heights. Vibration of steel stacks is discussed and economic factors in stack selection are considered. ASTM A 283, Grade C steel is recommended for welded stacks. Vitrified paving brick lining with lumnite-silica sand mortar backing between brick and stack shell, or lumnite-silica sand gunite lining reinforced with heavy wire mesh anchored to stack plates, are used for steel stacks. No additional plate thickness is provided for corrosion of lined stacks although top course has minimum ⅜-inch plate thickness. Unlined stacks have minimum corrosion allowance of 1/16-inch. Graphs, 6 references.—INCO. 9885

8. INDUSTRIES

8.1 Group 1

8.1.3, 4.4.5

High Chemical Stability Assures Long, Attention-Free Performance of Sealed Refrigeration Systems. V. A. WILLIAMITIS. Gen. Motors, Frigidaire Div. *Gen. Motors Eng. J.*, **2**, No. 1, 22-29 (1955) Jan./Feb.

Review of research leading to improvement of chemical stability within refrigeration systems. Development of highly stable refrigerants, lubricants and motor insulation have minimized major deteriorating factors, heat and catalysts. Contamination as a deteriorating factor is reduced by intensive drying and evacuating procedures and rigid control of processing. Stator of electric motor contains insulating materials such as phenolic plastic wire coating, paper slot and coil insulators, cotton coil tying string and cotton lead-wire insulation. Graph shows results of tests on effects of water on Freon 12 decomposition, using steel and copper strips as catalysts, as in an actual refrigeration system. Illustrations, 13 references.—INCO. 9905

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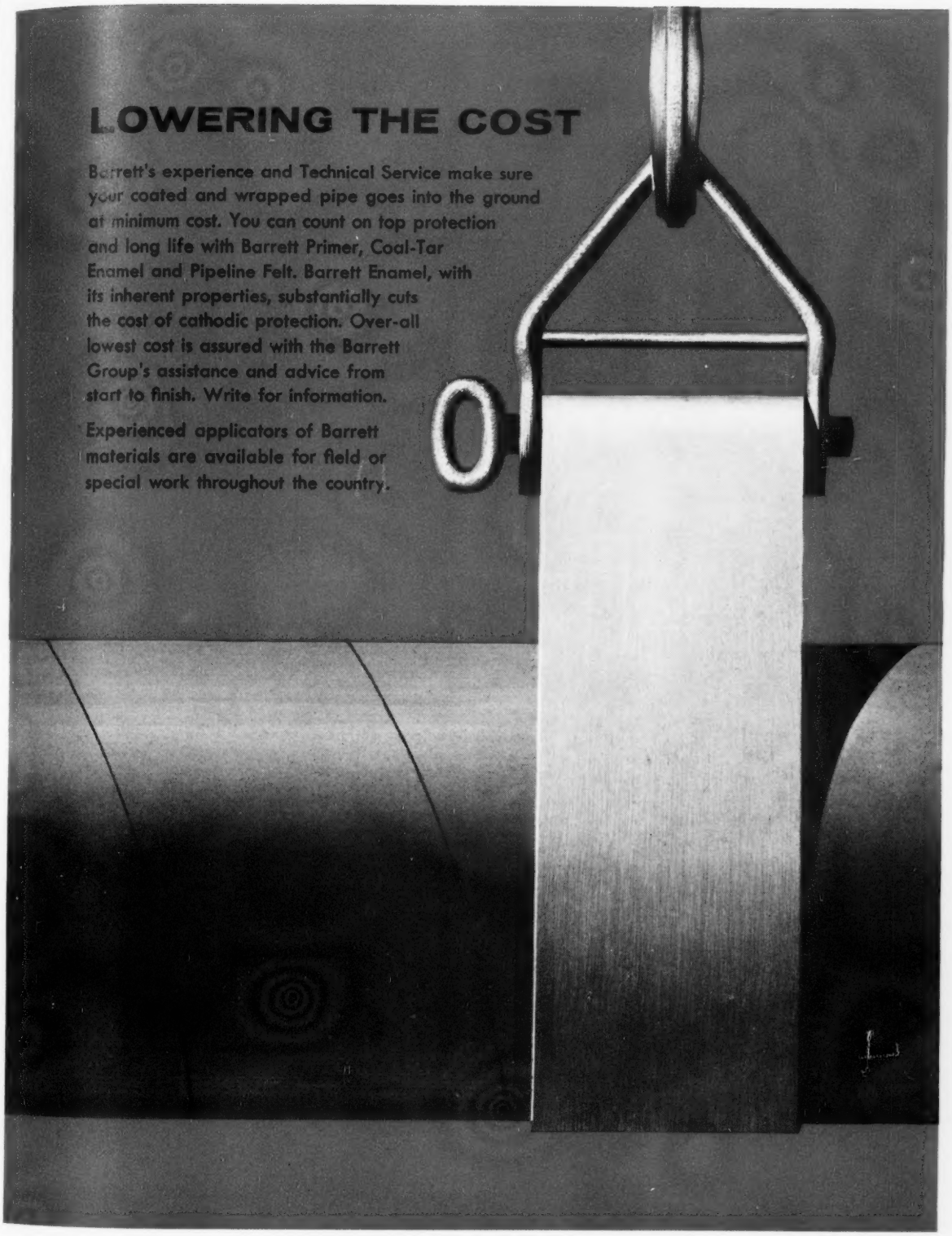
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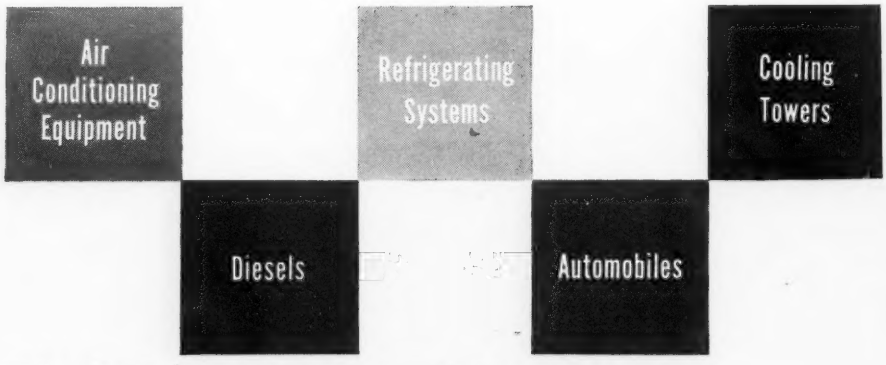

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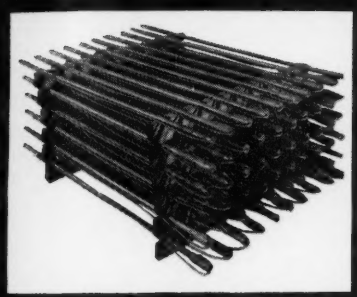
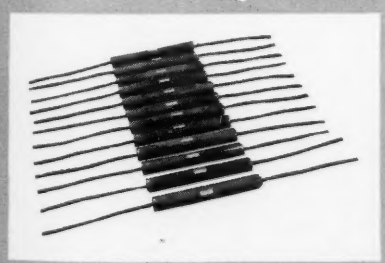


Qualitative reports now available on DURIRON® in cathodic protection service

Many of these reports are available now. More are currently in preparation for early release. If you feel that your present method of protection could be improved, we urge you to let us send you these reports as they become available. They more than confirm our reports of laboratory results!



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